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DIFFERENTIAL CHARACTERISTICS OF CONDITIONED EYELID RESPONSES ESTABLISHED BY REFLEX AND VOLUNTARY REINFORCEMENT [1]

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Although the traditional conditioning situation employs an involuntary unlearned reaction for the unconditioned or reinforcing response, other types of unconditioned responses have been studied. Pavlov (9) described secondary conditioning in which the reinforcement was itself a conditioned response. Other experimenters have employed as unconditioned responses simple instructed voluntary reactions such as squeezing a rubber bulb, moving the forearm or hand in a prescribed manner, or turning a crank. The resulting conditioned responses show sufficient similarity to those based on reflex reinforcement that a clear distinction has never been drawn. For example, Guthrie (3) does not believe it necessary to consider the way in which the unconditioned response is elicited. "The essential thing is that the response occur, whether we know just what stimuli are responsible for it or not. If the response occurs, such stimuli as accompany

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it tend to become substitute stimuli for the response" (p. 37). And Rexroad states that "The essential requirement for conditioning is that a stimulus regularly precede a response, whatever the cause of that response" (14, p. 144).

Certain considerations, however, make it reasonable to expect that the manner of eliciting the reinforcing response would be an important variable in determining the nature of the conditioned response. Comparison of the functional characteristics of conditioned responses based on reflex and on voluntary reinforcement should be carried out in situations which are as nearly identical as possible, and with complete recording of the responses. The eyelid reaction in human subjects was utilized for this purpose. Two types of reinforcement were used:

1. *Reflex-Reinforced Responses.*—A light stimulus, which evoked minimal or no lid reflexes, was paired at an interval of 400 ms. with an air-puff stimulus to one eye which evoked a brisk maximal corneal reflex. The conditioned response appears as a lid closure movement following the light and preceding the air-puff.

2. *Voluntary Reinforced Responses.*—The same light stimulus was followed at an interval of 300 ms. by a medium intensity sound stimulus (click), to which the subjects had previously been instructed to respond by winking voluntarily. The click itself evoked no reflex lid movements in most subjects, and the small reflexes given by other subjects adapted out in the course of a few trials. The reaction time of the voluntary response was approximately 100 ms. longer than the latency of the reflex to air-puff, so the reinforcing responses occurred at about the same interval (450 ms.) following the conditioned stimuli in both situations.

Comparison of the two kinds of conditioned response has been studied with respect to (1) their descriptive characteristics, (2) the course of acquisition and extinction, and (3) the differential effects of certain alterations in the experimental procedure.

Apparatus and Method

Movements of the eyelid were recorded photographically with the Dodge pendulum photochronograph by a procedure which has been described in detail elsewhere (Dodge,

1). An artificial paper eyelash attached to the left eyelid projected into a beam of light and cast a shadow across the vertical camera slit (see Fig. 1). The subject's head was stabilized by a support giving contact to the chin and the forehead.

The conditioned stimulus was the sudden presentation of a light by means of a silent electromagnetically controlled pendulum shutter. At a verbal ready signal which preceded the conditioned stimulus by 3 to 10 seconds, the subjects looked at a dimly illuminated window of opal flashed glass in the center of which was a black cross for a fixation point. Two kinds of light stimuli were employed with different groups of subjects: (1) *Central stimulus.* The illumination of the opal glass changed from 0.05 apparent foot-candle to 5.0 apparent foot-candles. (2) *Peripheral stimulus.* No change in the illumination of the opal glass occurred, but a weak reflection of the light appeared on the wall of the room at a point about 60° lateral to the line of fixation. While the stimulus was reported as seen by all subjects they thought it was not part of the experiment and paid no attention to it until it was specifically pointed out.

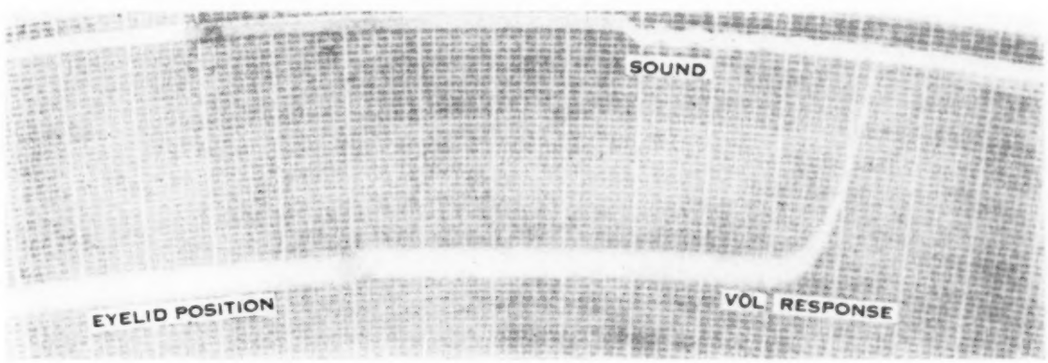

FIG. 1. Specimen record of the voluntary reaction to the click before conditioning. The record of lid position is the shadow cast by a paper fastened to the eyelid; a rise in the line indicates lid closure. The vertical time lines indicate 10 ms., with emphasized lines at 50 ms.

The air-puff stimulus which elicited the corneal reflex was delivered by automatic control from a nozzle directed toward the outer corner of the right eye. The stimulus strength employed was sufficient to elicit a maximal reflex in all subjects.

The auditory stimulus for the voluntary eyelid response was the click of an electromagnetic relay. A record of the time of stimulation was obtained with a signal marker on the camera. Calibration showed that the recording marker followed the sound by an interval of 15 ms., and this correction has been made in all reported latencies.

Subjects in these experiments were 45 Yale University students, none of whom were acquainted with the nature of the experiment. The two types of instructions and the two orders of procedure employed will be described in connection with the various experimental groups.

RESULTS

Voluntary-Reinforced Responses. Group I.—The establishment of a conditioned response to light by reinforcement with an instructed voluntary response to a click presented

300 ms. later was studied in 10 subjects. The experimental conditions were planned to provide as perfect a parallel as possible for the customary training with reflex reinforcement. The conditioned stimulus was the *central* light. This will be referred to as *stimulus C*. After the subject was adjusted in the apparatus and the two stimuli demonstrated to him, he was read *instructions A:* "The only stimuli which will be presented are the light which you just saw, and the click which you heard. These will always be preceded by the word 'ready.' When you hear this ready signal, be sure to have your eyes open and look at the cross. When you hear the click you are to blink your eyes as rapidly as you can. There is nothing else that you have to do. You may wish to close your eyes occasionally to avoid fatigue, or to shift your arms or legs. Do not move your head, however, and when you hear the word 'ready,' look steadily at the cross."

The order of presentation of trials is designated as *procedure 1*. Before paired stimulation was begun, 10 records of the voluntary response to the click were taken, and five records of any reflex response to the light stimulus alone. Fifty paired presentations followed, separated by from 25 to 50 seconds. A control trial in which the light was omitted was interpolated after each group of 10 training trials. An extinction series of five presentations of the light alone was followed by 10 trials in which the subject was reinstructed to give rapid voluntary winks to the click alone. The experimental conditions for this group can be referred to, for comparison with other groups, as *C A 1*, denoting respectively the nature of the stimulus, the instructions, and the procedure.

The results were decidedly different from typical conditioning studies. The conditioned response was a brisk complete eyelid closure, resembling the instructed voluntary response in every respect (Fig. 2). No alterations in amplitude or form resulted from training. The latency of the responses ranged from 180 ms. to 395 ms., with the median at 362 ms. That is, the typical response occurred after the click had sounded but before a voluntary response to the click

would have been possible.[2] Conditioned responses were very infrequent, appearing on only 12 percent of all the trials. Individual subjects gave responses on from 2 percent to 24 percent of their trials. There was no progressive increase in frequency during the training, and the individual learning curves seemed unaccountably irregular. Except for one subject, no responses appeared after the first of the extinction trials.

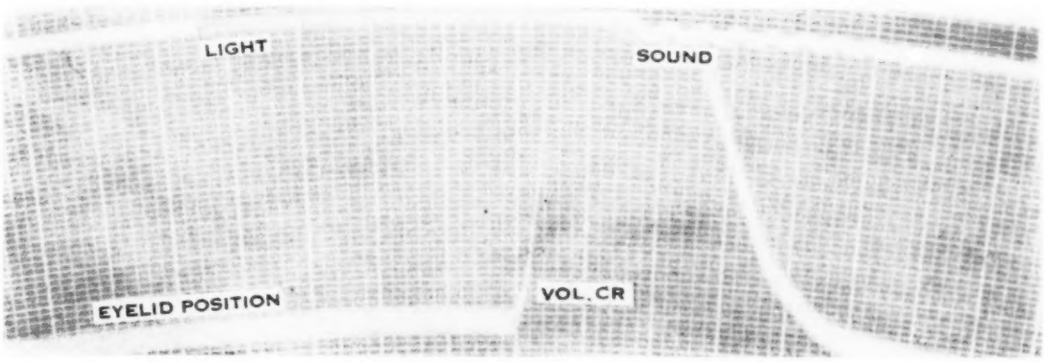

FIG. 2. Specimen record of the conditioned response developed by voluntary reinforcement.

A possible reason for the low frequency of conditioning was offered in the verbal reports of the subjects who, in describing the experiment at its termination, said variously that they "waited for the click," "tried not to notice the light," etc. It seemed indeed that they had instructed themselves to discriminate between the light and the click, reacting only to the latter. This is not a difficult discrimination for college students, and it is not surprising that the incidence of conditioning was not higher. Objective confirmation of the operation of a discrimination set is obtained by comparing

[2] The mean reaction time to the click on the 10 trials preceding and following the training when the subject was instructed to give rapid responses was 151 ms. and the minimal reaction time was approximately 105 ms. Any response, therefore, which occurred within 100 ms. after the click was considered a conditioned response. Tabulation of the latencies of reactions for each subject demonstrated that this criterion could be applied without distorting the results. Recalculation of all the data, considering only responses which preceded the click, reduced the number of conditioned responses to approximately one-third but did not alter the direction of the comparisons among any of the groups.

the mean [3] reaction time to the click during training (190 ms.) with that of the uncomplicated simple reaction during the 10 trials preceding and following the training (151 ms.).

Group II.—The experimental conditions for the second group of 10 subjects were changed in three respects intended to eliminate or reduce the discrimination attitude by making the light a very inconspicuous element of the situation. (1)

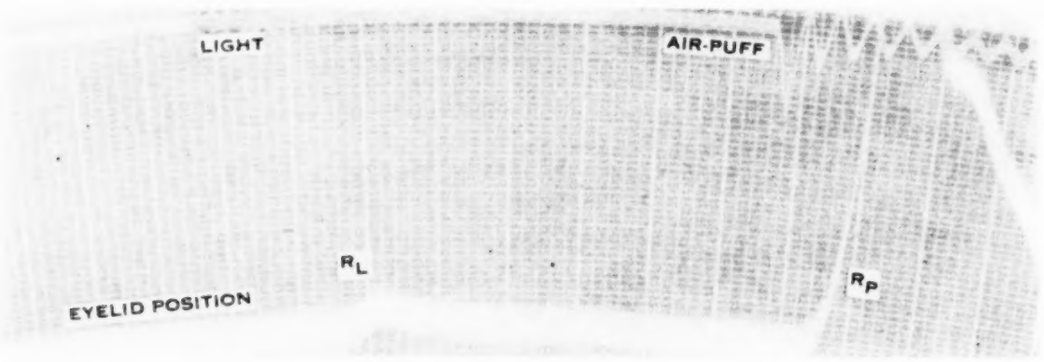

FIG. 3. Specimen record of the corneal reflex evoked by the air-puff. This subject also has a small reflex to the light.

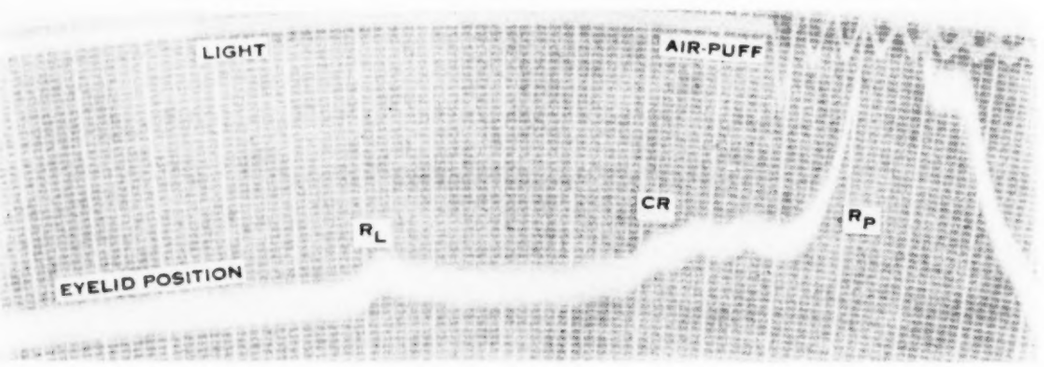

FIG. 4. Specimen record of the conditioned response developed by reflex reinforcement.

The conditioned stimulus was the weak peripheral light (*stimulus P*). (2) The instructions were altered so that no

[3] Although the median is ordinarily a better measure of central tendency of latencies, the mean is used in this connection because it is desired to secure an index of the subjects' set for simple or for discrimination reactions. Most subjects gave both long and short latency reactions, and the mean is the better measure to indicate the relative contribution of the long-latency reactions. The few instances in which no reaction occurred within the 350 ms. possible on the photographic record have not been included.

mention of the light stimulus was included (*instructions B*). (3) The procedure was modified to eliminate the presentations of the light or click alone before training, which might serve to call attention to the fact that there were two experimental stimuli. In addition, the control trials following each group of 10 training trials were omitted (*procedure 2*). Other conditions for the fifty paired stimulations were identical.

The change in procedure was evidently effective for six subjects of the ten (nos. 11–16, Fig. 5). They gave conditioned responses on from 59 to 92 percent of the trials. That this increase is associated with a loss of the discrimination set was obvious from their verbal reports, for none of them mentioned the light stimulus in describing the experiment. When it was called to their attention they said that while they had seen it they did not think it was intended as a part of the experiment. The reaction time to the click during training was much shorter for these subjects (133 ms.) than for those of group I (190 ms.), or for the remaining 4 subjects of group II (219 ms.). Of the 4 subjects who failed to show any appreciable conditioning, two spontaneously described their attempt to avoid blinking to the light, while the other two, although not verbalizing their discrimination attitude, showed long reaction times.

Groups III–V.—Since groups I and II differed in three aspects of the experimental conditions, it became a matter of interest to determine which of the differences were primarily responsible for the increased incidence of conditioned responses. Accordingly three groups of five subjects were trained under conditions which differed in only one respect each from those of group II. The conditions and results are summarized in Table 1.

For group III the stimulus (*P*) and procedure (2) remained the same as for group II, but the instructions (*A*) were those employed with group I; namely, the instructions which called attention to the light as one of the stimuli to be presented during the experiment. This change in instructions, however, had only a minimal effect in inducing a discrimination attitude, for the mean reaction time to the click was increased

TABLE 1

COMPARISON OF THE CHARACTERISTICS OF CONDITIONED VOLUNTARY RESPONSES ESTABLISHED UNDER FIVE DIFFERENT EXPERIMENTAL PROCEDURES

Group	N	Experimental Conditions	Frequency of Conditioned Responses (Percent)	Mean Reaction Time to Click (ms.)
I	10	Stimulus *C*, instructions *A*, procedure 1.	12	190
II	10	Stimulus *P*, instructions *B*, procedure 2.	47	154
III	5	Stimulus *P*, instructions *A*, procedure 2.	34	176
IV	5	Stimulus *C*, instructions *B*, procedure 2.	16	180
V	5	Stimulus *P*, instructions *B*, procedure 1.	11	206

only 22 ms. over group II, and the conditioned response was present in almost as great frequency. Analysis of the incidence of conditioned responses during the course of the 50 trials indicated that group III, more than any other group, displayed a kind of learning curve. The percentage frequency of responses increased during the successive fifths of the training as follows: 18, 30, 42, 39, 44. It would appear that the instructions induced a discrimination set at first which was rapidly forgotten in the course of the experiment.

More effective in decreasing conditioning were the change of the conditioned stimulus from the peripheral to the central light (group IV), and the change from procedure 2 to procedure 1 (group V). The frequency of conditioned responses for the two groups was 16 and 11 percent respectively. This is very little greater than group I (12 percent) in which all three conditions favored the discrimination attitude. Some of the subjects indicated by verbal report that their attitude was essentially a discrimination set, and the objective data on the mean reaction time to click confirmed this. Although the conditions for group IV were not significantly more favorable for conditioning than those of group V, the mean reaction time was considerably shorter. This is probably be-

cause the stronger central light, while just as conducive to a discrimination attitude as procedure 1, is at the same time easier to discriminate from the click than is the peripheral light, and consequently permits a shorter discrimination reaction time.

The comparison of the group averages does not disclose the full extent of the relationship between frequency of conditioning and the degree of discrimination set because the experimental conditions were not always effective in forcing the same attitude on the part of all subjects. It was pointed out earlier that in group II six of the subjects showed numerous conditioned responses while four showed very few. Similarly, in group III subject 21 differed markedly from the group average, giving responses on 73 percent of the trials with a mean reaction time to the click of only 150 ms. In group IV, subject 26 gave responses on 65 percent of the trials, with a reaction time to the click of 141 ms. Analysis of the data by individual subjects shows an even closer dependence of conditioning upon reaction time than is revealed by the group comparisons. Figure 5 indicates that high incidence of conditioned responses is present only in subjects whose reaction time is less than 160 ms. This signifies a simple rather than a discrimination reaction, for the average latency of the uncomplicated reaction to the click was 151 ms. The rank order correlation computed from the data of Fig. 5 is $-.77$.

Some of the subjects, moreover, did not maintain a consistent attitude throughout the fifty trials of their training. The data for six individuals who showed the most marked changes in amount of conditioning have been selected for presentation in Table 2. Four of these reached a maximum in the final stage of the training, while the other two (1, 25) had a maximum early in the session, with a subsequent decrease. In all cases, however, there is a close correspondence between the trend of conditioning and the trend of reaction times, the absence of appreciable conditioning being associated with the longest reactions to the click. The rank order correlation computed from the data of Table 2 is $-.68$.

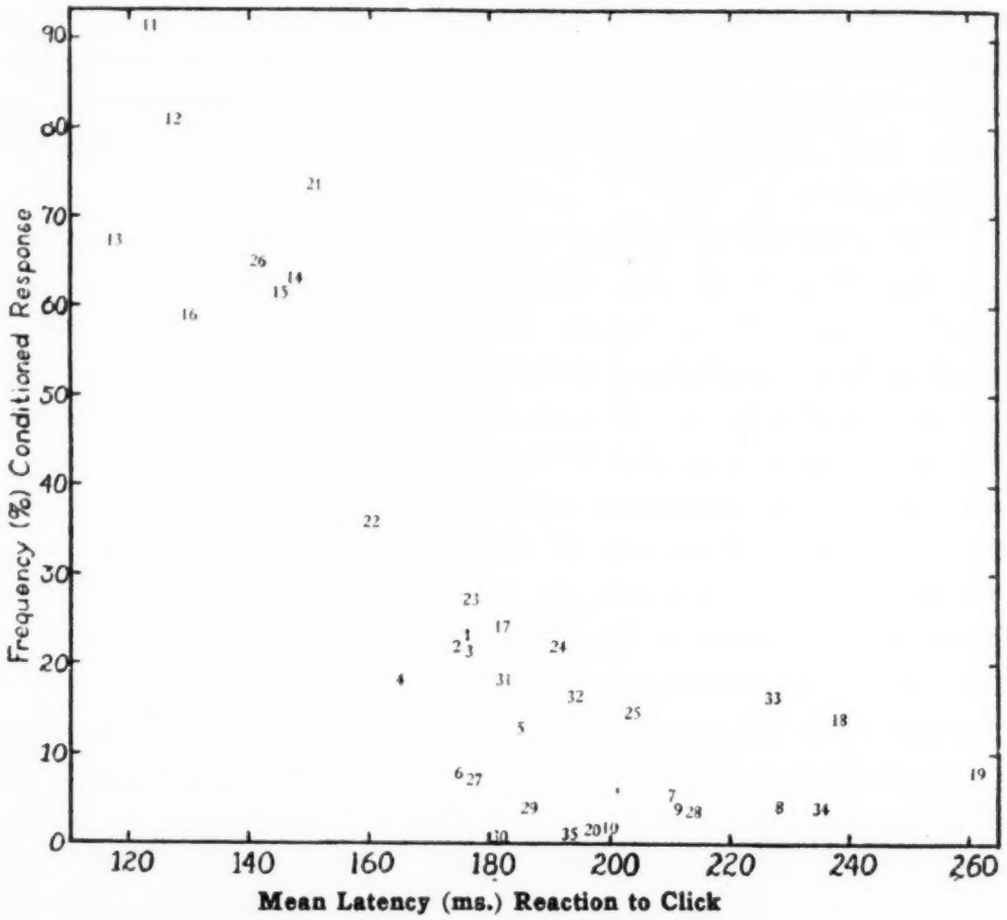

FIG. 5. Scatterplot showing the relationship between amount of conditioning in terms of frequency and the mean reaction time to the click for the 35 subjects comprising groups I–V. The numbers serve to identify the individuals of each group as follows: 1–10 group I, 11–20 group II, 21–25 group III, 26–30 group IV, 31–35 group V.

Reflex-Reinforced Responses.—The characteristics of the conditioned eyelid response reinforced by the corneal reflex to an air-puff have been studied in detail by Hilgard and Campbell (**6**) in 51 subjects. The experimental conditions of their study are as comparable as possible with those of group I of this experiment. The subjects were college students, and the method of recording lid responses was identical. The nature and intensity of the conditioned stimulus and the order of the trials in the experimental procedure were identical; the instructions used for group I differed only by the addition of directions for the voluntary wink to the click.

The conditioned response which develops with reflex-reinforcement is a partial lid-closure occurring between the

TABLE 2

INDIVIDUAL EXAMPLES OF ALTERATION OF SET WITHIN THE TRAINING SERIES, SHOWING THE RELATION BETWEEN INCIDENCE OF CONDITIONED RESPONSES (PERCENT CR) AND MEAN REACTION TIME (IN MS.) TO THE CLICK (RT)

Subject	Group	Conditions		Trials				
				1–10	11–20	21–30	31–40	41–50
1	I	CA1	Percent CR	0	30	60	20	10
			RT	275	176	115	151	165
6	I	CA1	Percent CR	0	0	0	0	40
			RT	210	193	175	166	120
23	III	PA2	Percent CR	10	10	30	30	56
			RT	210	223	151	118	122
25	III	PA2	Percent CR	0	50	20	0	0
			RT	180	139	207	217	305
26	IV	CB2	Percent CR	20	40	80	90	91
			RT	257	145	127	117	127
32	V	PB1	Percent CR	10	10	10	0	56
			RT	215	232	203	182	164

light and the puff stimuli (Fig. 4). It has a characteristic form, with slow and often irregular recruitment. It first appears as a very small response, and increases in amplitude as well as in frequency during the course of training. The latency of the response decreases progressively until it approximates the latency of a voluntary lid response to light. Extinction is gradual, the amplitude decreasing progressively from 22.4 mm to 2.7 mm in ten trials.

A further comparison between responses based on voluntary-reinforcement and reflex-reinforcement is possible by studying the effect of changed experimental conditions upon the two types of response. The change from group I to group II produced a marked increase in the frequency of the voluntary-reinforced conditioned responses. What would be the effect of a comparable change on reflex-reinforced responses? Utilizing Hilgard and Campbell's results as a counterpart of group I, another group of 10 subjects (group VI) were trained with reflex reinforcement under conditions equivalent to group II of this study. The conditioned stimulus was the

weak peripheral light; the instructions were analogous to instructions *B* in that no reference to the light stimulus was made; and the procedure (2) included no isolated presentations of the light or air-puff. Table 3 presents a comparison of the results of this group and those of the Hilgard and Campbell group. The amount of conditioning, measured in terms of frequency of responses or in terms of amplitude, was decidedly less in group VI. The same change of conditions that produced an increased strength of voluntary-reinforced responses caused a decreased strength of reflex-reinforced responses.

TABLE 3

COMPARISON OF CONDITIONED EYELID RESPONSES BASED ON REFLEX REINFORCEMENT UNDER TWO DIFFERENT EXPERIMENT CONDITIONS (SEE TEXT FOR DESCRIPTION)

The data on amplitude in the Hilgard and Campbell group are from their published paper (1936), while the frequency results were kindly supplied for this purpose by Dr. Hilgard.

Trials	Group VI		Hilgard and Campbell	
	Amplitude	Frequency	Amplitude	Frequency
	(*mm*)	(*percent*)	(*mm*)	(*percent*)
1–10	0.4	5	1.5	16
11–20	1.8	12	4.8	42
21–30	2.9	22	8.4	61
31–40	4.0	29	10.7	68
41–50	4.2	32	12.4	72
Average	2.7	20	7.6	52

No further experiments were performed to determine which of the three changes in conditions was primarily responsible for the reduction of the reflex-reinforced responses, but from incidental experiments with a few subjects and from the results on other responses (Hovland, **8**), it seems likely that the decrease in the intensity of the conditioned stimulus is a sufficiently important factor to account for most of the loss in conditioning.

Summary.—The comparison of the voluntary-reinforced conditioned responses (VCR) with the reflex-reinforced conditioned responses (RCR) may be summarized under three heads:

(1) *Descriptive Characteristics.*—The VCR is a brisk, continuous, complete lid closure; the RCR is a slow, recruiting, incomplete lid closure. The VCR has a median latency which is about 150 ms. longer than that of the RCR.

(2) *Modification with Training.*—The VCR appears within the first few trials and shows no progressive increase in frequency with further training. The amplitude (complete closure) does not alter. The RCR develops more slowly, increasing progressively in frequency and amplitude for at least 50 trials. The latency of the VCR does not show any great change with training; there is some dropping out of very fast and of very slow responses which leaves the median about the same. The median latency of the RCR decreases progressively with training until it finally approximates the latency of a voluntary reaction to the conditioned stimulus (200 ms.). The VCR undergoes abrupt extinction, usually in one trial; the RCR shows a progressive diminution in amplitude and frequency and an increase in latency during extinction.

(3) *Effect of Changed Experimental Conditions.*—The change from the *CA1* conditions of group I to the *PB2* conditions of group II resulted in a marked increase in the frequency of the VCR. The same change in conditions produced a large decrease in the strength of the RCR.

Discussion

Gibson (**2**) has raised the question whether genuine conditioning on the basis of voluntary reinforcement is possible. This is partly a question of pure definition. The conditioning situation is usually specified as the repeated presentation of an indifferent stimulus in definite temporal relation to another stimulus which evokes a response. The conditioned response is then the response which comes to be evoked by the conditioned stimulus. The voluntary-reinforced conditioned response can be subsumed under this definition because it is not originally given to the conditioned stimulus, and appears only after paired presentation (Stephens, **16**). Moreover, as Razran (**13**) has pointed out, there

is nothing in the tradition of the study of conditioning to rule out the use of voluntary reactions as unconditioned stimuli. The significant question, then, is whether the same principles govern the voluntary-reinforced as the reflex-reinforced conditioned responses. The results of the present study indicate that this is not true.

A further differentiation between reflex-reinforced and voluntary-reinforced conditioned responses has been pointed out by Stephens (**15**). Subjects were instructed to respond to one signal by hitting a target with a stylus in the left hand, and to respond to a second signal by a similar movement with the right hand. After repeated paired presentations in which one signal was regularly followed by the other, conditioning was tested for by presenting only one signal on certain trials scattered randomly among the training presentations. Moving the hand for which no signal had been given was considered a conditioned response. Although such responses were obtained when either the first or the second signal was presented alone, they were much more frequent in the latter case. By definition this is 'backward conditioning,' and the fact that it was more frequent than forward conditioning in this voluntary-reinforcement situation is further evidence of the functional differentiation from reflex-reinforced conditioned responses.

Yacorzynski and Guthrie (**17**) have reported a study comparing conditioned hand movements based respectively on voluntary-reinforcement and on electrical stimulation of the motor nerve to the flexors of the fingers. At a short interval following a buzzer signal, the shock was administered to the left ulnar nerve. The subject was instructed to squeeze a balloon with the right hand when the shock was felt. Conditioned movements appeared in both the right and left hands on the test trials with the buzzer signal alone. The characteristics of the voluntary-reinforced conditioned response of the right hand were essentially the same as those of the voluntary-reinforced lid response of this study. No learning curve was found, the frequency of responses actually decreasing with continued training. The amplitude was approxi-

mately the same as for the instructed response. Extinction was very rapid. When the buzzer was presented alone for one trial in the midst of training the number of conditioned responses was decreased on the next few trials (compare the effect of procedure 2 of this study).

The conditioned response of the left hand, reinforced by the motor nerve stimulation, was considered an example of reflex reinforcement, but this is open to serious question. The unconditioned response is not a reflex, but a motor tetanus. Conditioning based upon such reinforcement constitutes a very complex situation. It has been shown by Hilgard and Allen (**5**) that conditioning will not take place under such conditions unless a supplementary facilitating set is established by instructions. Presumably such a set was furnished in the experiment of Yacorzynski and Guthrie by the instructions to move the right hand. Under these conditions it might be expected that the resulting conditioned response would show greater similarity to voluntary-reinforced responses than to reflex-reinforced responses, and the results bear out this supposition. The authors point out that the conditioned responses of the left hand resembled the voluntary-reinforced responses of the right hand in many respects: extinction was rapid; excited subjects showed more conditioning; there was a positive correlation between extent of reinforcing response and frequency of conditioning; responses could occur without the subject's awareness; no increase of strength or of certainty of response occurred with repetition. Three differences between the left and right responses were noted, none of which may be crucial: The greater amplitude of the voluntary response of the right hand may be merely the result of the different method of recording the movement. The shorter latency and decreasing frequency of the right hand response undoubtedly are a function of the different reinforcement for the two hands, but may indicate merely two kinds of voluntary-reinforcement as well as anything else.

There is good reason to believe that some common types of reinforcement, not ordinarily so considered, are similar to voluntary reinforcement in many respects. Such for

example might be the finger withdrawal from shock which has been extensively employed as an unconditioned response. The average latency of finger movement to intense single shocks is 120 ms. (Hilden, 4). This is clearly longer than flexion reflex latencies, and falls within the range of voluntary reaction times. It is not unusual to discover some subjects who do not withdraw from the shock until they are directed to do so. Moreover, the nature of the withdrawal movement is not stereotyped as most reflexes are, but is definitely a function of the position of the hand with reference to the electrodes. If these considerations establish the voluntary nature of the withdrawal response, the characteristics of the conditioned response based on finger shock become more understandable. This conditioned response has been found to be quite atypical of reflex-reinforced responses, and shows many features similar to the voluntary-reinforced responses described in the present study (see review by Razran, 11). It may also be expected that the presence of shock in the experimental situation will result in certain differences from the simple voluntary-reinforcement conditions.

From the available evidence of the present experiment and of related investigations it appears that one of the most important factors determining the conditioning of voluntary reactions is the subject's attitude or set. This factor also influences reflex-reinforced conditioned responses, as Razran (12), Hilgard and Humphreys (7), and others have shown, but to a much less significant degree.

The necessary data for a complete understanding of the influence of attitudes in voluntary conditioning are not at present available, but a few general principles are obvious. The greatest difference will appear between conditions in which the subject considers the conditioned response 'correct' or 'incorrect.' In the former case, exemplified by the task of code-substitution, a single conditioned response is established completely in a single trial,[4] and learning can be studied

[4] An illustration of this was unintentionally provided by one subject (not included in the experimental series) whose records showed that under the conditions of group III he gave conditioned responses on every trial at a latency of about 200 ms. When he was questioned later it was discovered that he had misunderstood the instructions and thought he was supposed to wink to the light!

only when a multiplicity of responses is required and interference among them limits the progress of achievement. In the latter case, of which the present experiment is an example, conditioning will never occur unless the subject is 'tricked' into responding falsely. He is continually on guard to prevent mistakes, and the success of the conditioning will be a direct measure of the ingenuity of the experimenter. The most effective devices which have been employed to secure voluntary conditioning are the use of speed instructions, short or variable time intervals between stimuli, extraneous stimuli, distraction; in short, anything which will serve either to minimize the subject's set to discriminate between the conditioned and unconditioned stimuli, or to confuse the subject so that successful discrimination is difficult.

The particular characteristics of the voluntary-reinforced conditioned response which have been pointed out above are probably a function of the voluntary nature of the conditioned response, and are not limited to responses based upon voluntary-reinforcement. A highly voluntary conditioned response can undoubtedly arise from reflex reinforcement provided the subject has the response already in his repertory of voluntary behavior. An example of this situation was noted in an individual (subject 13, group 2) who was given training with reflex reinforcement on the day following the training with voluntary reinforcement. He continued on the second day to give voluntary responses of exactly the same sort as appeared on the first day, and at almost the same frequency.

The definition of a voluntary response is not simple, and no categorical distinction between voluntary and involuntary responses is possible (Peak, **10**). In speaking of a conditioned response as voluntary, it is not implied that a reportable intention is necessary, but rather that the response is highly susceptible to the effects of instructions and attitudes in contrast with the relative dependence of involuntary responses upon objective stimulus conditions.

Conclusions

Comparison was made of the functional characteristics of two types of conditioned eyelid responses established under

comparable experimental conditions (1) with reinforcement by an instructed voluntary wink, and (2) with reinforcement by the corneal reflex elicited by an air-puff.

The two types of conditioned responses showed marked differences in their descriptive characteristics, their modification during training, and in the effect of alterations in experimental conditions and procedure. Although the voluntary and the reflex winks used for reinforcement are identical movements, it is clear that the conditioned response developed with one is entirely different from that developed with the other.

A most important variable in determining the nature and strength of voluntary-reinforced conditioned responses is the degree and efficiency of the subject's set to discriminate between conditioned and unconditioned stimuli, as revealed objectively by his reaction time to the unconditioned stimulus.

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THE NATURE OF THE RESPONSE RETAINED AFTER SEVERAL VARIETIES OF CONDITIONING IN THE SAME SUBJECTS *

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I. Introduction

What sort of a response will be retained and reproduced after an interval, when there are several alternate possibilities? If a subject has been previously trained to make different reactions to the same conditioned signal, which reaction will be called out at a later time? Suppose that some of the formerly learned responses are conflicting or mutually inhibitory and yet that all have been associated with a single conditioned stimulus. Suppose that some have been more frequently repeated than others, and again, that some have been learned much more recently than others. Will the Law of Frequency or the Law of Recency prove dominant?

That conditioned responses can be retained for relatively long intervals is a well established fact. Reproduction of CRs in sheep after 2 years has lately been demonstrated by Liddell, James, and Anderson (**5**) while Marquis and Hilgard (**6**) have found the conditioned eyelid response to be still present in a dog with a brain lesion after 16 months. A number of conditioning studies containing retention data for both human and animal subjects have already been reviewed and summarized by Razran (**7, 8**) and by Hilgard (**2**). The mere proof that effective retention is possible is not then the concern of the present experiment. Its object is rather to discover what sort of a response will be reproduced when several different possibilities are offered. It is essentially a study of the basic nature of the responding movement.

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II. Procedure

The experimental data have grown out of a series of observations by one of the present writers, on the bilateral transfer of conditioning in dogs (3, 4). The same animals which had been used in these previous studies were kept and retested after intervals of varying length. Some of them were subsequently conditioned in new and different ways so as to form the basis of retention tests for additional sorts of responses.

General Method.—In order to obtain comparative data it was necessary for the subjects to develop several distinctive responses to the same conditioned stimulus in the same or in equivalent experimental situations. The buzz-shock technique was therefore used in all varieties of conditioning. The responses conditioned were different sorts of flexion responses of the front feet (*vide infra*). Subjects were placed in a solid wooden stock mounted upon a table, with the forepaw or forepaws to be conditioned fastened to light balanced levers. Pneumographic and flexion responses were automatically recorded, together with buzz, shock, and time in units of a fifth-second.

The unconditioned stimulus was a faradic shock delivered immediately below the wrist. It was adjusted through a potentiometer to be just strong enough to give a maximal flexion of 4 inches permitted by the apparatus. If an animal lifted his foot to a height of *ca.* 2½ inches, the shock was automatically cut out by a mercury switch mounted on the lever-arm to which the paw was fastened. The conditioned stimulus was a buzz of medium intensity with a frequency of approximately 60 cycles. The buzz was sounded for 2 seconds and the shock overlapped the buzz for the last .2-sec. of the two-second period. Successive trials were spaced at 15 to 120 seconds and were given in daily series of 20. Approximately on every tenth and twentieth stimulation of a series, the shock was omitted by E. One-tenth of the stimulations were thus control buzz-alone trials; the remainder during all of the conditioning (not extinction) series were paired buzzes and shocks.

The criterion of conditioning adopted in each of the different sorts of training was 19 CRs of an inch or more in height within a daily series of 20 stimulations. No animal was considered to be completely conditioned until it attained this criterion, regardless of the type of conditioning involved. In the various extinction procedures, a response was not considered to be completely extinguished until the subject had gone through a daily series of 20 buzzes, without making a single flexion response to 19 of the 20 stimulations.

These criteria are somewhat difficult, and admittedly arbitrary. They have the effect of grouping the trials into units analogous to statistical class-intervals or step-intervals. They emphasize efficiency of performance during any one daily series at the expense of a good or mediocre performance on successive days. In theory, a subject could make CRs to the last 18 of his 20 stimulations on one day, and make 18 more CRs to the first 20 stimulations on the next succeeding day. He would then have responded with 36 consecutive CRs. Still, by our criterion, he would not be conditioned, because he had failed to make 19 CRs in 20 within a single day's performance. These criteria have the further effect of reducing computations of the total number of trials required to reach a given criterion of learning to some multiple of 20. If only buzz-shock trials are considered (the control buzz-alone trials being eliminated) then the trials required to reach a specified criterion are always multiples of 20, less 10 percent of the total.

Kinds of CRs Observed.—In addition to incidental behavior such as struggling, barking or howling, conditioned breathing, salivation, defecation, and urination, the retention of 4 specific kinds of flexion conditioned responses was observed. All of these CRs were conditioned at different times to the same buzz stimulus—some without extinction of the previously conditioned CR, and some after extinction of the previously conditioned CR. The responses for which retention tests were made were:

1. Simple conditioning of the right forepaw

2. Simple conditioning of the left forepaw.

3. Ambiguous conditioning. Conditioning of the ambiguous variety results in some animals when the unconditioned shock-stimulus is transferred to the left forepaw after complete conditioning of the right (3). When the new left-foot CR develops *before* the previously established right-foot CR is extinguished, the total reaction to the buzz is said to be ambiguous. Ambiguously conditioned animals not infrequently lift both feet simultaneously or in rapid succession to the buzz stimulus. In such cases it is necessary for the subject to support the weight of the forepart of his body by pressing downward against the wooden collar of the stock.

4. Bilateral conditioning. Here the shock is delivered simultaneously to both forepaws at the end of the buzz-period, so that the subject is deliberately trained to lift both feet to the conditioned stimulus. Bilateral conditioning produces a kind of behavior which is similar, if not identical in some cases, to ambiguous conditioning. There are these fundamental distinctions between the two:

a. The animal which is ambiguously conditioned receives *shocks in only one foot at a time.* In the beginning during his right-foot training he was shocked on the right side. Later, he is shocked only on the left side. He himself develops the reaction of lifting both feet to the buzz. In bilateral conditioning, however, the shock which is delivered to both feet demands that he lift both feet together from the start. If an animal raises only one forepaw to the buzz, he will be shocked in the one which is not raised and so is forced to make a latent reflex withdrawal of that foot also.

b. In ambiguous conditioning the dual response is thus *successively built up.* The left-foot CR is added to the right-foot CR which was present when left-foot training began. In bilateral cconditioning the movements of the right and left forepaws are simultaneously, not successively, conditioned.

c. With continuous training, *ambiguous conditioning weakens.* The response of the non-shocked foot is extinguished in a few hundred trials at most. Bilateral conditioning does not weaken with repeated pairings of buzz plus shock. Instead it strengthens.

III. Results

A total of about 5,000 stimuli spread over a period of more than a year were administered to the 6 animals for which retention data are available. Those subjects which received the greatest amount of training went through the following sorts of conditioning and extinction series (given here in their correct order): simple conditioning of the right forepaw, extinction of the right-foot CR, reconditioning of the right forepaw, conditioning of the left forepaw, extinction of ambiguous conditioning, extinction of the left-foot CR which

remained when the right-foot lifts of ambiguous conditioning had been eliminated, and bilateral conditioning.

In addition to these types of training and extinction, retention tests were introduced whenever warranted. A retention test consisted, without exception, of one daily series of buzzes without shock. Retention was thus tested entirely by the method of reproduction. Every such test as far as the subject was concerned was in itself a series of 20 extinction trials. The tests therefore served partially or wholly to extinguish the CRs which were being measured by them. Time intervals which elapsed between training or extinction, and the tests of retention which were given, ranged from 1 to 6 months.

Frequency versus Recency.—The best evidence as to the relative influence of frequency and recency in the retention of conflicting CRs is furnished by the data on right- and left-foot conditioning. All 6 animals were first conditioned to flex the right forepaw, the CR was then extinguished and immediately reconditioned; they were next conditioned to lift the left forepaw. Many more right-foot stimulations were therefore given than left-foot stimulations. This was due in part to the fact that the right foot was both conditioned and reconditioned, in part to the fact that there was a great deal of positive transfer from right- to left-foot conditioning, and in part to the fact that in some of the animals a considerable number of 'overlearning' trials were given in the training of the right foot. There was no overlearning in the left-foot training.

The relative numbers of right- and left-foot stimulations for 5 of the subjects are presented in Table 1. The totals

TABLE 1

NUMBER OF R- AND L-FOOT STIMULUS-PAIRINGS OF BUZZ PLUS SHOCK RECEIVED BY 5 DOGS DURING CONDITIONING SERIES *

Dog	M2	M3	M4	M5	M6	Total
R	630	270	162	378	378	1818
L	108	72	108	126	90	469
R/L	5.83	3.75	1.50	3.00	4.20	3.88

* Non-shock control trials are excluded from these figures.

given here apply only to shocks (sent to the right or left sides) plus buzzes. None of the control or buzz-alone trials are considered. For 1818 right-foot stimulations received by these 5 subjects, there were only 469 left-foot trials, or a ratio of nearly 4 to 1. Frequency is thus overwhelmingly in support of the right-foot as against left-foot CRs.[1]

In Table 2 are presented the results of retention tests on these same animals, from 1 to 6 months after the termination

TABLE 2

FREQUENCY OF R- AND L-FOOT CRS TO BUZZ ALONE AFTER INTERVALS OF FROM 1 TO 6 MONTHS

Dog	Retention Interval	No. of Stimuli Given	Response Data		
			Side	CRs	No Response
M3	1 month	20	R	0	20
			L	1	19
M4	1 month	20	R	0	20
			L	12	8
M6	2 months	20	R	0	20
			L	5	15
M2	3 months	20	R	0	20
			L	3	17
M5	3 months	20	R	2	18
			L	19	1
M4	6 months	20	R	0	20
			L	3	17

of the left-foot training. With a single exception, the subjects all gave left-foot CRs and no right-foot CRs when tested later with buzz alone. Even in the case of M5, which made the only right-foot CRs of the entire group, the score was 19 left- to 2 right-foot responses in the 20 buzzes given.

Figures 1 and 2 show portions of graphic records made before and after the time intervals indicated, for 2 of the

[1] The record of the sixth subject, F1, is not included in Table 1, since F1 is the only dog of the 6 which received more left- than right-foot stimulations.

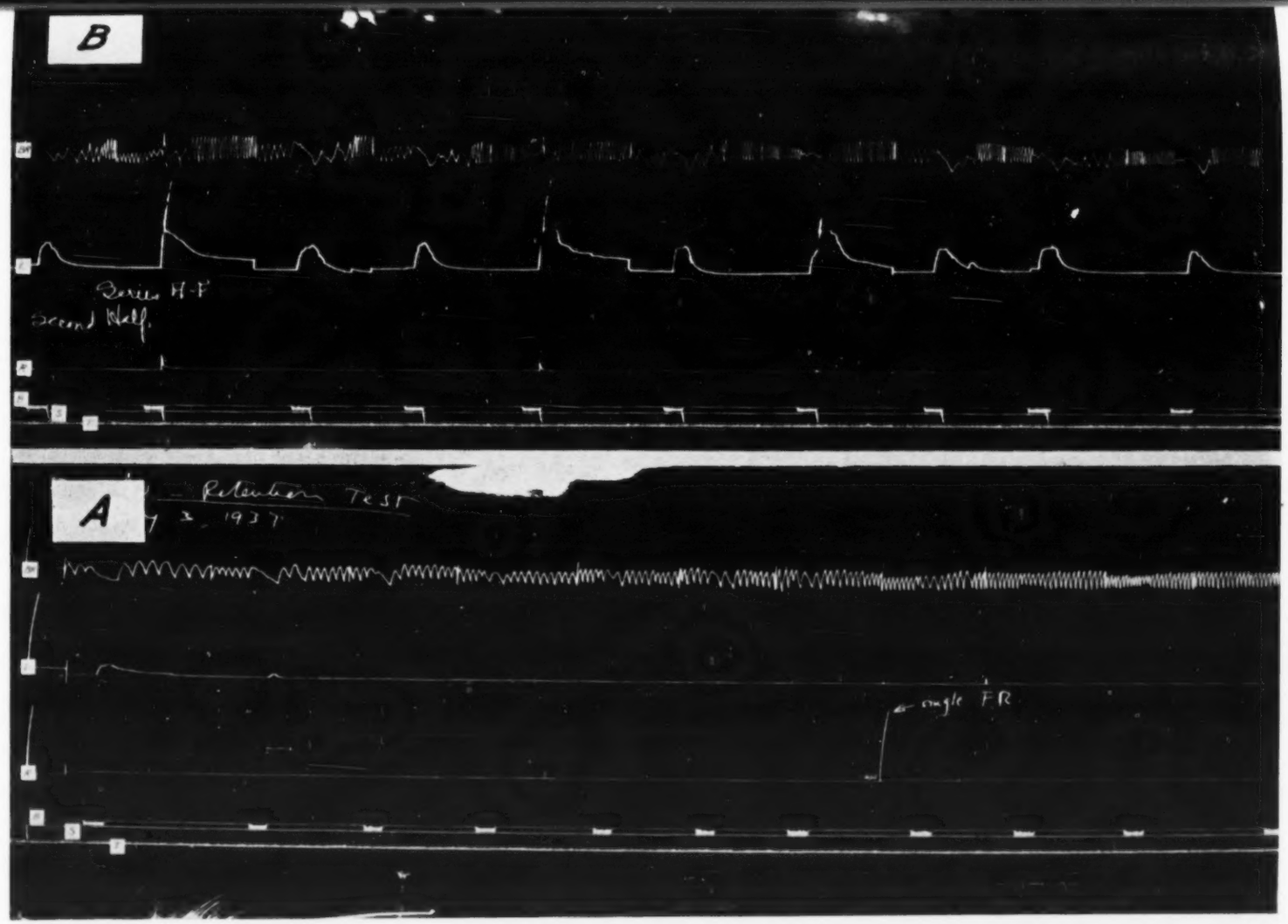

FIG. 1. Retention of a right-foot CR to buzz alone after an interval of 3 months. This subject was given a total of 630 shocks (paired with buzz) to the right forepaw, followed by 108 shocks (paired with buzz) to the left forepaw. The right-foot CR was hence much 'overlearned' before left-foot training began. Record B shows the nature of the responses made just before the three-month interval. Record A, made at the end of the period of retention, shows that left-foot CRs only were reproduced, in spite of the overwhelming preponderance of right-foot stimulations which were originally received. (Top line = respiration. Second from top = left foot. Third from top = right foot. Third line from bottom = buzz. Second from bottom = shock. Bottom line = time in fifth-seconds. Records are for subject M2.)

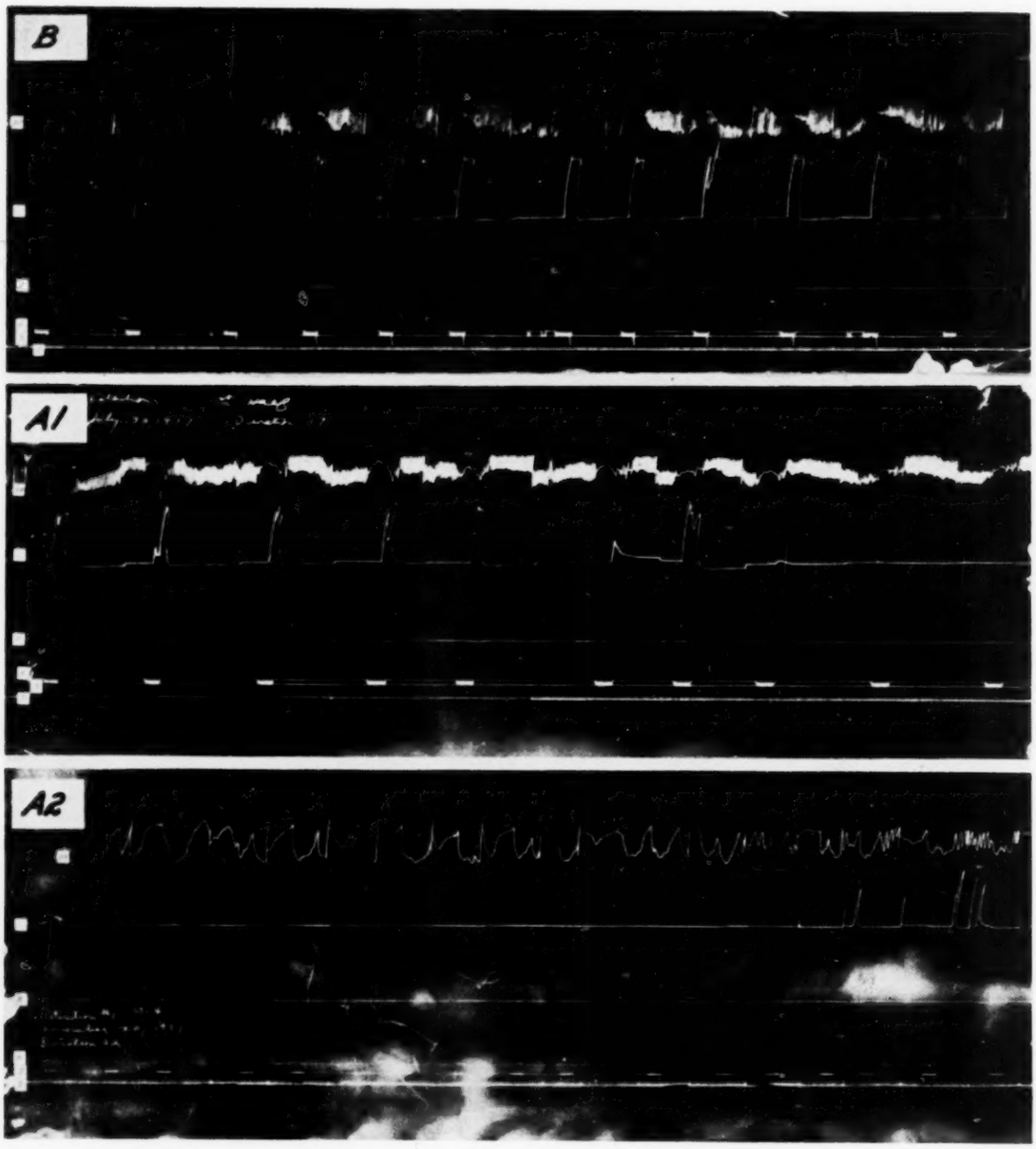

FIG. 2. Retention of a right-foot CR after intervals of 1 month and 6 months. Subject received 168 right, followed by 108 left stimulations of buzz plus shock, yet only left-foot CRs were reproduced when the buzz alone was presented later. Record B shows the last CRs made prior to the interval of retention. Record A1 is the retention test after 1 month. Record A2 shows retention after 6 months. There was no reconditioning between A1 and A2. (Top line = respiration. Second from top = left foot. Third from top = right foot. Third from bottom = buzz. Second from bottom = shock. Bottom line = time in fifth-seconds. Records are for subject M4.)

subjects. The last performance just previous to the interpolated time period and the first performance during the retention test are reproduced. In both of these figures, the top line is the respiration record, the second line from the top shows the activity of the left foot, the third line from the top is the right-foot record, then in order come the buzz, shock, and time lines. Time units are in fifth-seconds. It will be noted from Fig. 1 that, although M2 received nearly 6 times as many right- as he did left-foot trials (630 as against 108), he gave not a single right-foot CR after an interval of 3 months.

The performance of M4, who was tested twice without any intervening reconditioning, at intervals of 1 and 6 months, is shown in Fig. 2. Only left-foot responses were given in the retention tests (A1 and A2), in spite of the fact that the subject originally received nearly two-thirds more right- than he did left-foot stimulations. The behavior which occurred is particularly interesting because of the long delay interval employed with this animal. Since the left-foot training came immediately after the right-foot training, a long delay might be thought of as minimizing the special recency effects of one sort of training over the other, by placing both of them so far in the subject's past. If recency is in effect 'dominating' frequency, then as the advantage of recency decreases, it might be supposed that the advantage of frequency would increase. Applying such reasoning to the case of M4 would mean that even though he gave no right-foot CRs after 1 month he might be expected to do so after 6 months. The experimental findings furnish no support for such a view.

The Kind of Movement Retained.—Perhaps the most obvious interpretation which presents itself regarding the importance of recency in this sort of a situation is the fact that the right-foot response had been extinguished and the left-foot response had not. Why should the right-sided reaction persist after a time interval? Through the process of extinction the subjects may be said, in fact, to have learned *not* to raise the right foot. Hence their failure to lift it at a later date was as much proof of what they had learned as were the actual CRs made on the left side.

Such a proposal may indeed be correct as far as the right- and left-sided training already examined is concerned. But subsequent findings from other sorts of conditioning go beyond such an interpretation as we shall presently show. The thesis proposed in this paper is that the responding movements, which are made at the time training is interrupted, are essentially the same as the responding movements which will be made upon the resumption of training. To paraphrase a much quoted statement of Guthrie (1, p. 32) that "The movement that occurs will be the movement conditioned," we would say *the movements most recently conditioned will be the movements reproduced.* Such a principle has the effect of practically eliminating the law of frequency as a factor determining the strength of retention. Frequency is only important in building up the response 'most recently conditioned.' Retention of CRs would then become essentially a continuation of the recency principle with no more than an indirect relation to frequency. Previously learned reactions, although they may have been more frequently associated with the conditioned stimulus, seem never to be called out in preference to subsequently developed reactions.

Ambiguous Conditioning.—A good method of testing such a view is afforded through ambiguous conditioning. Ambiguous conditioning has been found to be a stage or aspect of the process of bilateral transfer. It represents a state in which a part of the process is magnified or slowed down to an extent that is roughly analogous to slow-motion cinematography. Although ambiguous conditioning may continue for several hundred trials in some dogs, it can eventually be reduced to unilateral performance. It does not occur in all animals.

The complete process of bilateral transfer of the flexion CR is ideally diagrammed in Fig. 3. The upper part of the figure represents what may be called *un*ambiguous transfer, while the lower portion shows the ambiguous aspects of the process. The solid line in both graphs traces the development of the left-foot CR and the broken line is the extinction curve for the right forepaw. The region in which complete ambiguity

continues at the 100 percent level is indicated by a rectangle in the lower chart.

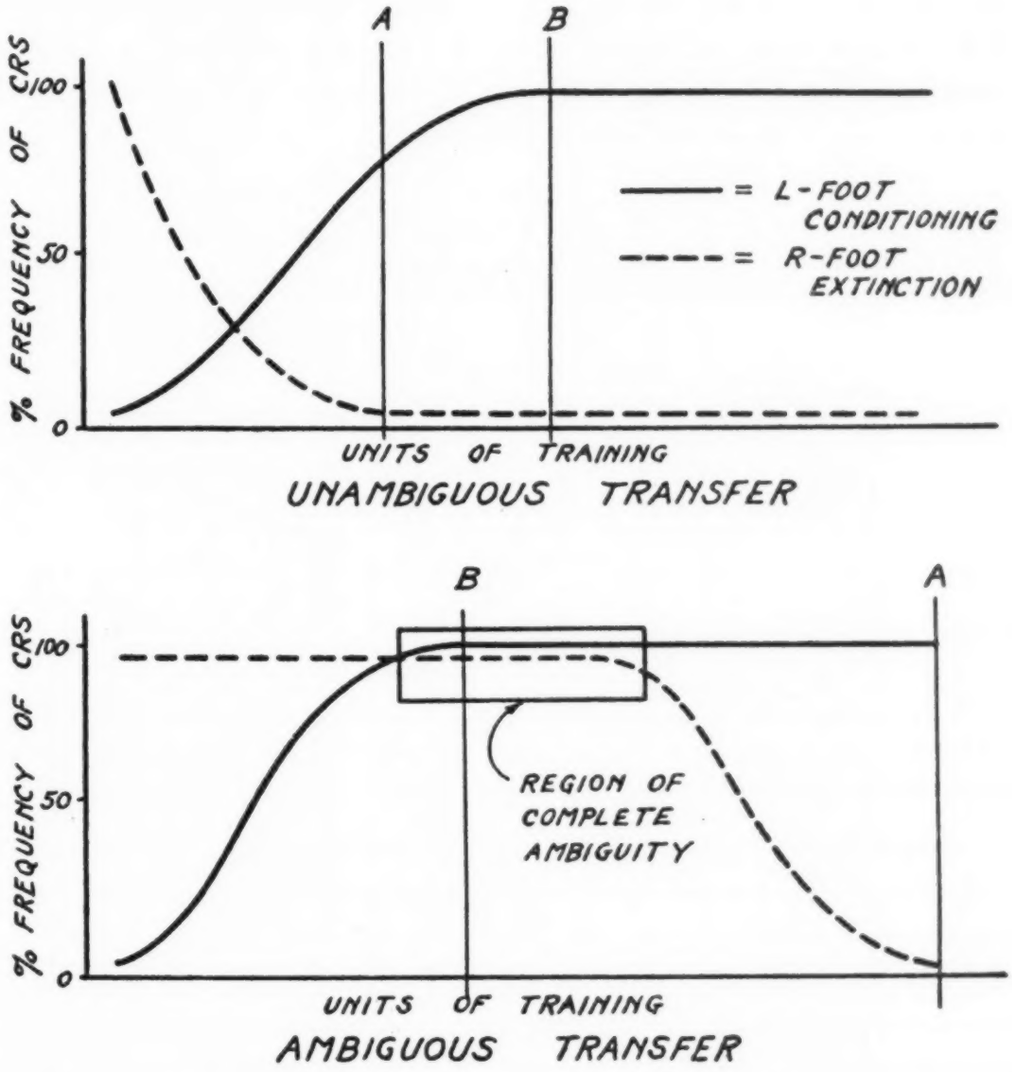

FIG. 3. Ideal conditioning and extinction curves for ambiguous and unambiguous transfer of the flexion CR in dogs. When the shock is transferred from the right to the left forepaw (after complete conditioning of the right forepaw by the buzz-shock technique), the modification in behavior follows one of the two arrangements pictured. The extinction of the right-foot response may *precede* the conditioning of the left foot, as in the upper part of Fig. 3. Or the right-foot extinction may be delayed until after the left-foot conditioning has become well established, as in the lower part of the figure. In such instances a subject will lift both forepaws nearly simultaneously to the buzz for a large number of trials. This phenomenon has been called ambiguous conditioning.

The fundamental difference between ambiguous and *un*-ambiguous transfer is that in *un*ambiguous transfer, the extinction of the right-foot CR is complete before the left-

foot CR is developed (see *A* and *B*, upper part of Fig. 3). But in ambiguous transfer, the left foot is conditioned long before there is any evidence of extinction of the right-foot CR (see *B* and *A*, lower part of Fig. 3).[2] There is then a concomitant or ambiguous lifting of both feet to the buzz even though one foot only is shocked.

TABLE 3
FREQUENCY OF R- AND L-FOOT CRS TO BUZZ IN 2 AMBIGUOUSLY CONDITIONED ANIMALS

Dog	Retention Interval	No. of Stimuli Given	Response Data			
			Side	CRs	Unacceptable Rs*	No Response
M5.....	1 month	20	R	13	5	2
			L	8	2	10
F1.....	1 month	21	R	9	7	5
			L	11	8	2

* Unacceptable Rs are doubtful or uncertain responses which were ruled out by the experimenters. In most cases such responses are lifts which are part of a more general bodily movement or struggle which was in progress when the buzz was sounded.

Suppose now that training in ambiguously conditioned subjects is interrupted when the performance is as indicated within the rectangle in the lower portion of Fig. 3. In this case extinction plays no part in determining the nature of the response retained and reproduced. It is clear also that the ambiguous performance is simply a temporary or unfinished stage in the process of bilateral transfer. Table 3 gives the CRs of 2 such animals, M5 and F1, after a retention interval of 1 month. Bilateral or ambiguous lifts were consistently given after the time interval, just as they had been given before it.[3]

[2] Dogs which condition ambiguously are not necessarily slow learners when it comes to developing new CRs. But they are much slower at the process of extinction. It has recently been found in our laboratory that subjects which condition ambiguously are slower than non-ambiguous animals in extinguishing simple CRs of both right and left forepaws, as well as in ambiguous extinction.

[3] The behavior before and after retention tests of ambiguous conditioning is so like that shown in Fig. 4, for bilateral conditioning, that no kymographic reproductions of ambiguous behavior have been presented here. Kymographic tracings showing ambiguous CRs have previously been published by Kellogg and Walker (3).

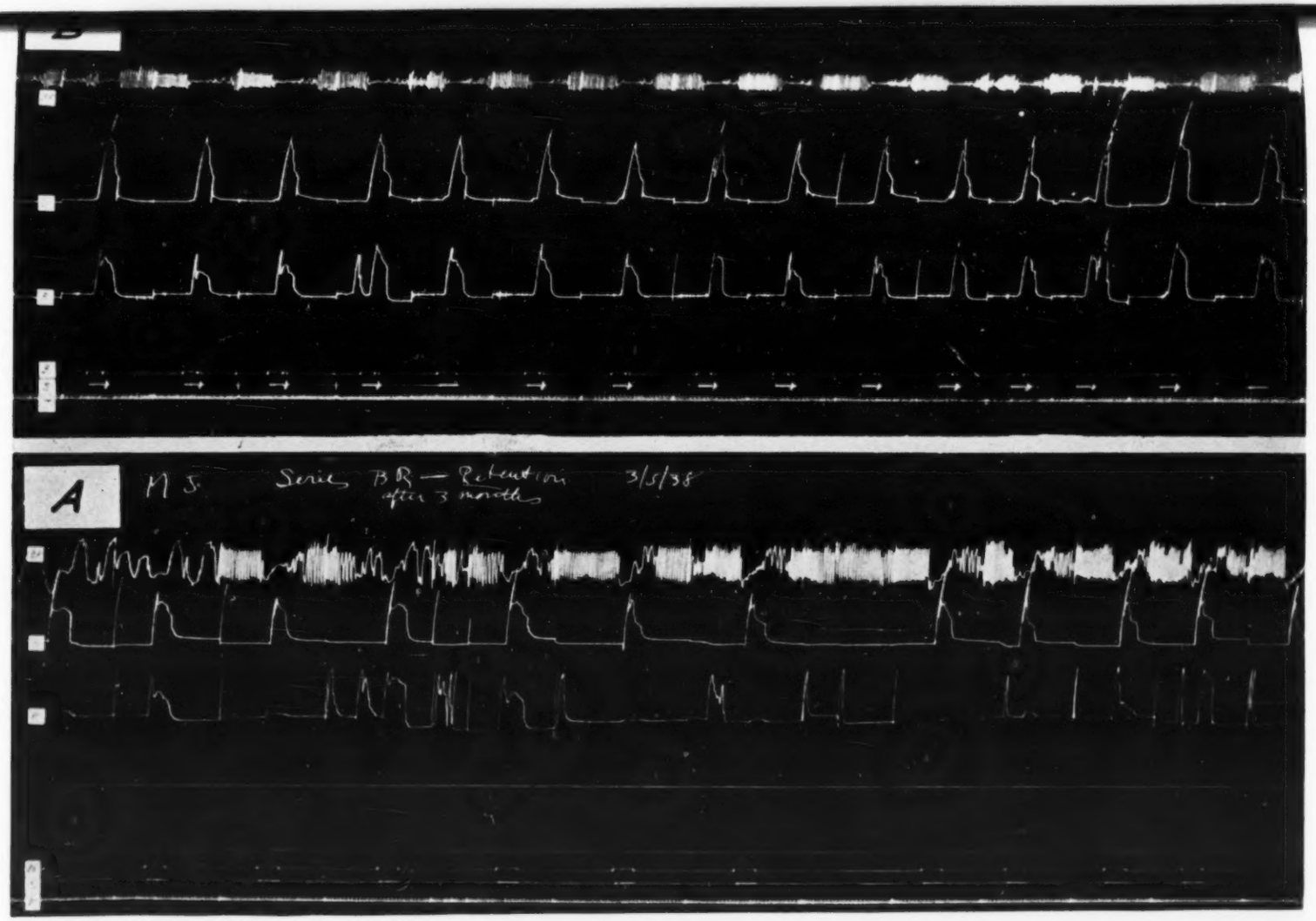

FIG. 4. CRs reproduced to buzz alone 3 months after the termination of *bilateral conditioning*. During bilateral training the subject was simultaneously shocked in *both* forepaws while the buzz was sounded. When conditioning was complete he lifted both feet together to the buzz. Record B shows bilateral performance after about 60 pairings of buzz plus shock-to-both-forepaws. Record A shows bilateral CRs to buzz alone when the three-month interval had passed. Before bilateral conditioning was undertaken this animal had already received nearly 1100 buzz or buzz-shock stimuli in other sorts of conditioning and extinction tests. (Top line = respiration. Second from top = left foot. Third from top = right foot. Third line from bottom = buzz. Second from bottom = shock. Bottom line = time in fifth-seconds. Records are for subject M5.)

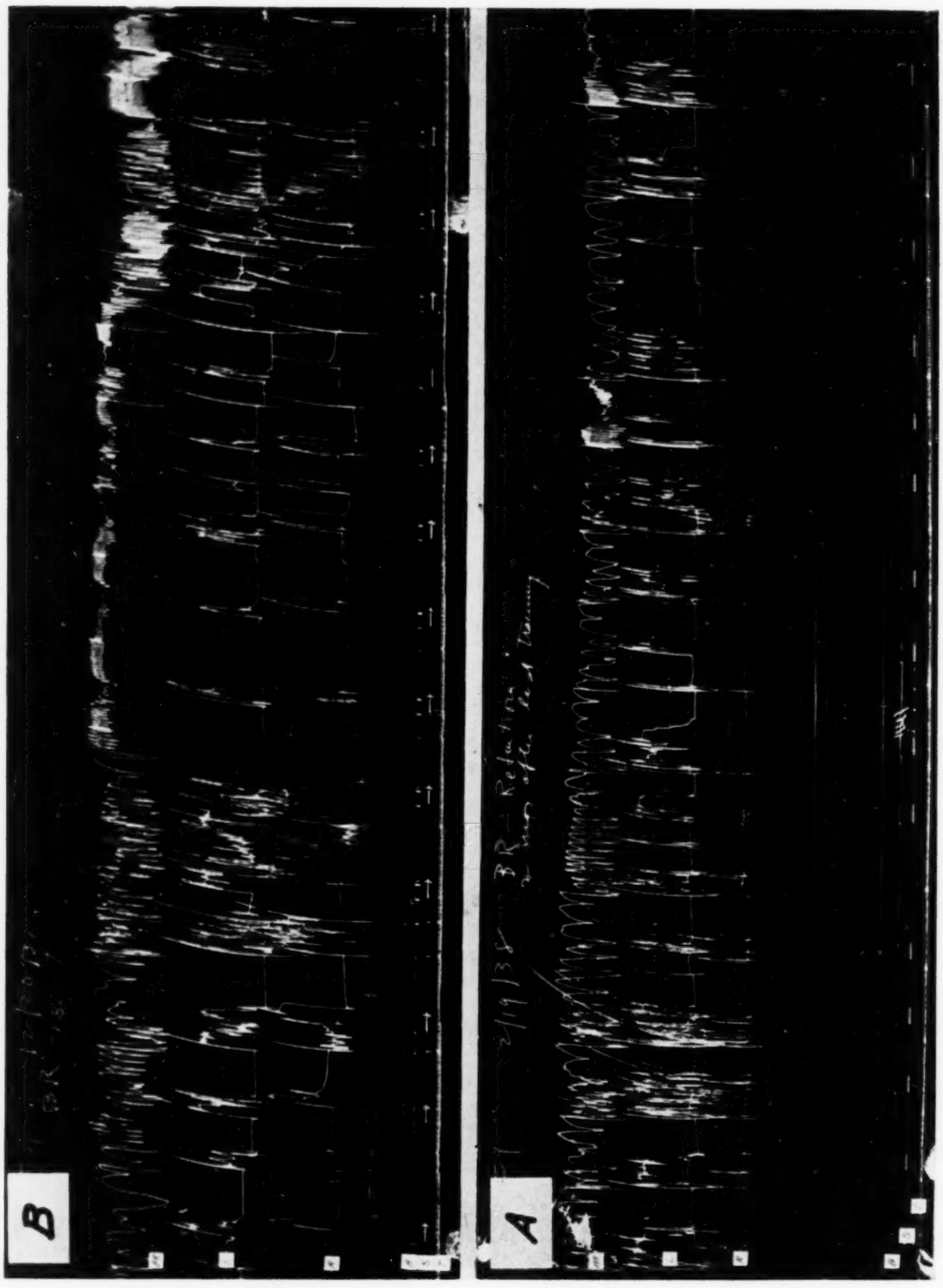

FIG. 5. These records show struggle and other individual characteristics of behavior which were present before and after the interpolation of a two-months time interval. Subject was being trained in bilateral conditioning. During the last 20 of the 340 stimulations given, her performance was as indicated in record B. Two months later a retention test with buzz alone (record A) brought out most of the original peculiarities, including struggling, which were present when the training had been terminated. (Top line = respiration. Second from top = left foot. Third from top = right foot. Third line from bottom = buzz. Second from bottom = shock. Bottom line = time in fifth-seconds. Records are for

Bilateral Conditioning.—To test further the hypothesis that the movement most recently conditioned is the movement reproduced, 3 of the animals were later trained in bilateral conditioning. After complete extinction of all previous flexion CRs, they were shocked in *both feet simultaneously* at the end of the buzz period.[4] Two of these subjects, M4 and M5, reached the criterion of bilateral conditioning in 100 and 60 trials respectively, while the third, F1, had failed to reach it after 340 trials, at which time the training was discontinued.

The retention responses of M4 and M5 are presented in Table 4. Both subjects made a number of bilateral lifts,

TABLE 4

FREQUENCY OF R- AND L-FOOT CRS TO BUZZ IN 2 BILATERALLY CONDITIONED ANIMALS

Dog	Retention Interval	No. of Stimuli Given	Response Data			
			Side	CRs	Unacceptable Rs*	No Response
M4.....	3 months	20	R	16	0	4
			L	3	0	17
M5.....	3 months	20	R	13	6	1
			L	20	0	0

* Unacceptable Rs are doubtful or uncertain responses which were ruled out by the experimenters. In most cases such responses are lifts which are part of a more general bodily movement or struggle which was in progress when the buzz was sounded.

although the right-foot responses of M4 were more persistent than the left-foot responses. A sample of the pre- and post-retention performance of M5 is also given in Fig. 4. Bilateral CRs will be seen to be present to almost every buzz. The after-interval performance is thus essentially a duplicate of that at the end of the period of training.

Retention of Other Conditioned Reactions.—There were other responses which were observed to be a definite part of

[4] The total reaction of the organism when bilaterally conditioned is similar, if not identical, in some subjects to that present in ambiguous conditioning. There are, nevertheless, 3 fundamental differences between ambiguous and bilateral conditioning. These have already been pointed out in the section on procedure of the present paper.

buzz alone (record A) brought out most of the original peculiarities, including struggling, which were present when the training had been terminated. (Top line = respiration. Second from top = left foot. Third from top = right foot. Third line from bottom = buzz. Second from bottom = shock. Bottom line = time in fifth-seconds. Records are for

the behavior-picture in the conditioning of many of the animals. One of these was the respiration which conditioned rapidly. The modification produced was generally retained during the retention intervals as can be seen from examining Figs. 1, 2, and 4. Incidental reactions, not subject to graphic recording, which were also conditioned, were barking, movements of the tail, and the tensing of the leg and other muscle groups. For some of the subjects reactions of this sort occurred regularly *when the buzz was sounded* and must therefore be regarded as behavior which was conditioned specifically to the buzz. A second and different group of responses occurred not to individual buzzes but to the general conditioning situation of the stock and its surroundings. In this latter group of grosser or more generalized activities should be listed bodily tremor, excessive salivation, howling, biting or chewing of the wooden portions of the stock, struggling to get out, defecation and urination.

Whenever reactions of either group had become common and regular in an animal's behavior by the time the training of any particular flexion response was discontinued, it was observed that these same reactions would show themselves consistently in the retention series. A partial picture of the retention and reproduction of characteristically individual behavior of this sort can be seen in Fig. 5. Here are presented (in B) the recorded responses of F1 during the last 20 of the total of 340 trials which were given this subject in an unsuccessful attempt to condition her bilaterally. Struggling and violent activity are indicated both in the respiration and in the many lifts of both forepaws. The retention record (A), made 2 months later, contains so many of the individualities of the first record that the two could probably be identified as coming from the same animal, even though they were not labelled.

The behavior of M4 throughout his 11 months of laboratory work may be taken as an example of the conditioning of the grosser or more generalized reactions to the experimental situation itself. This dog had always been quiet and well behaved, and had never shown any evidence of conditioned

urination in the earlier phases of his training. Retention tests up to 6 months after original conditioning readily demonstrated this fact. After receiving a considerable number of shocks in both forepaws during bilateral conditioning, however, M4 developed conditioned urination to the experimental situation. It then became his regular and invariable reaction at each daily session. Such was the state of affairs at the termination of bilateral conditioning. Three months later, at the time of the retention test for bilateral conditioning, the urination response was still present, even though no shocks were given at all during the 20 retention trials. A careful habituating technique was then undertaken in the attempt to extinguish this reaction. In a few days the new training was successful, after which still another retention interval was allowed to elapse. The extinction of the previous response was now proven to be effectively retained, and the dog could be placed in the stock without further urination.

We thus have evidence of the retention of conditioned barking, conditioned breathing, conditioned tail movements and other striped-muscle responses to the buzz; and of the retention of tremor, salivation, howling, struggling, urination and defecation to the experimental situation itself. Observations of this nature, together with the data already presented on the retention of left-foot, right-foot, ambiguous and bilateral CRs, lend strong support to the principle that *the movements most recently conditioned will be the movements reproduced after an interval.*

IV. Summary

Approximately 5,000 stimuli were given to 6 dogs over a period of more than a year, in several kinds of conditioning and extinction. The buzz-shock technique was used throughout all of the training, and the reactions conditioned were all flexion responses of one or both forepaws. Subjects which received the greatest amount of training went through the following sorts of conditioning and extinction trials: simple conditioning of the right forepaw, extinction of the right-foot CR, reconditioning of the right forepaw, conditioning of the

left forepaw, extinction of ambiguous conditioning, extinction of the left-foot CR which remained when the right-foot lifts of ambiguous conditioning had been eliminated, and bilateral conditioning. Retention tests with the buzz alone as a stimulus were made after intervals up to 6 months. Among the principal findings were the following:

1. Even though many more stimuli were required to condition the right forepaw than were subsequently required to condition the left, the subjects uniformly retained and reproduced left-foot CRs after an interval, in preference to right-foot CRs.

2. This was because the left-foot training had always followed the right-foot training, and because the right-foot CR had been unconditioned or extinguished during or before the conditioning of the left foot. The subject's response at the time the training stopped was therefore (*a*) to make a left-foot CR, (*b*) *not* to make a right-foot CR.

3. In the process of transferring the CR from the right to the left forepaw, some subjects became ambiguously conditioned. Ambiguously conditioned animals lifted both forepaws to the buzz even though they were shocked in the left forepaw only.

4. When training was interrupted during the stage of ambiguity, the ambiguous reactions were also found to be retained after an interval. Unconditioning was not a factor in the reproduction of these responses.

5. After complete extinction of all previous responses, some of the subjects were then bilaterally conditioned. In this case the shock was delivered to *both* forepaws simultaneously. A bilaterally conditioned subject lifted both front feet to the buzz and supported the weight of the forepart of his body with his neck.

6. Bilateral conditioning was reproduced in all essential features in retention tests given 3 months after the end of bilateral training.

7. Other specific reactions which were conditioned to the buzz stimulus were also retained after interpolated time intervals. Among these were conditioned breathing, condi-

tioned movements of the tail, conditioned barking, and the tensing of certain muscle groups.

8. A number of grosser or more generalized responses were further conditioned, not to the buzz, but to the experimental situation itself. In this latter group of activities were urination, defecation, howling, bodily tremor, excessive salivation and struggling.

9. Each of these reactions was retained and reproduced after several months, by one or more of the animals.

10. The following law of principle seems best to govern the findings of this experiment: *The movements most recently conditioned will be the movements reproduced after an interval.*

11. Frequency therefore plays but a secondary role in the retention and reproduction of CRs of this sort. It seems to be important only in building up the response 'most recently conditioned.'

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SOME EFFECTS OF 'MENTAL SET' ON THE ELECTROPHYSIOLOGICAL PROCESSES OF THE HUMAN CEREBRAL CORTEX [1]

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With the introduction of the electroencephalographic technique in 1929 by Dr. Hans Berger (**5**), and with the subsequent verification of his original observations by Adrian and Matthews (**1**), Gibbs, Davis and Lennox (**9**), and Jasper and Carmichael (**11**), it became increasingly apparent that psychology had available a new tool which might be of value in uncovering some physiological correlates of 'mental' events.

All of these pioneer investigators reported changes in the electrocortical record when a subject engaged in 'mental' activity. Later and more delimiting studies by Bagchi (**3**), Knott (**13**), Loomis, Harvey and Hobart (**15**), Travis (**16**), Travis, Knott and Griffith (**18**), and Travis and Knott (**19**, **20**) added to the body of experimental proof that there is a relationship between the electroencephalogram, as a physiological index, and 'mental' activity.

Cruikshank (**6**), Jasper (**11**), Jasper and Cruikshank (**12**) and Travis and Hall (**17**) have made significant contributions to the correlation of sensation, and after-sensation, and electrocortical phenomena, thus demonstrating the availability of electroencephalography in psychophysiological studies.

Although the use of this new electrophysiological technique has been somewhat restricted, psychologically, to the study of sensation and centrally aroused processes, a few observa-

[1] The main content of a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, in the Department of Psychology, in the Graduate College of the State University of Iowa. June, 1938.

[2] The author wishes to express his gratitude to Professor Lee Edward Travis, who directed this research.

tions have been made with reference to the establishment of electrocortical correlates of action.

It is known by all workers in the field of electroencephalography that the effect of a light stimulus is to make the alpha wave of the record either less apparent (blocking) or more apparent (evoked potential). These changes are usually clear-cut and readily detectable by cursory examination. If a subject is given instructions to respond to such a stimulus in some prearranged fashion there is a change, in the aggregate at least, in the blocking of the alpha rhythm (**12**, **18**); and one of these investigations (**18**) has suggested that there is a change in the evoked potential effect. The change in the blocking effect is a change in degree rather than a change in kind and can be detected only by measurement and analysis. The latent time of blocking is found to be reduced when the stimulus leading to the blocking also serves as the stimulus for overt response.

Travis, Knott and Griffith (**18**) have reported this reduction in latent time of blocking and have statistically analyzed the results of their experiments. They placed their subjects in two experimental conditions, which they have labelled 'passive' and 'active.' In the passive condition the subject lay on a cot, eyes open, while a ½ watt neon bulb was aperiodically flashed. In the active condition the subject responded to this stimulus by raising the right hand. In the first condition the observed latent time of blocking was .287 sec.; in the second, .248 sec. The difference between these two values was reported to be statistically significant, the critical ratio (Diff./σ diff.) being 3.15. In relative terms, the reduction in latent time was about 14 percent.

Jasper and Cruikshank (**12**) have reported that the latent time of blocking of the alpha rhythm to light was .28 sec., SD, .12 sec., in an experimental condition where no *manual* response was made to the stimulus. When their subjects responded to the stimulus by depressing a finger reaction key, they observed an average latent time of .25 sec., SD, .08 sec. In a second response experiment, Jasper and Cruikshank gave a preparatory signal (tone) before the light stimulus

and the mean latent time dropped to .20 sec. The reaction time also dropped, from .45 sec. to .25 sec.; this probably means a change in the 'set' of the subject.[3]

Both of these investigations show that the fundamental sentence, "React to this light" (or some variant of such a sentence), can alter the response of the cortex to light. The results lead to a discussion concerning the meaning of such a reduction in latent time which is not, statistically at least, fortuitous; and such a discussion must lead to determining the answer to the questions: What factors are operating to reduce the latent time of blocking? How do they do so?

Problem

This investigation has been primarily concerned with the first question, "What is operating?"[4] This question can be attacked directly by experimental methods, whereas the second question is at present susceptible only to hypothesis.

Two arbitrary working hypotheses were set up at the outset of this investigation to clarify the issues involved in the understanding of the previous data and to systematize the experimental work to be presented here.

These two hypotheses were: (1) Some *centrally* maintained process correlated with the 'mental set' of the subject, which was set into operation by the instructions to the subject, so altered the functional structuring of the cortex that the observed latent times occurred. (2) Some *peripherally* maintained process, which was correlated with the 'mental set' of the subject, was set into operation by the instructions, so altering the functional structuring of the cortex that the observed latent times occurred.

'Functional structuring' is a concept which has been introduced by this writer (**13, 20**) to assist in the interpretation of the electrical activity of the cortex. Its meaning is essentially literal, since it is difficult to think of 'function'

[3] These investigators have not calculated the statistical significance of their observed differences, nor have they published sufficient data for such calculations to be made.

[4] A preliminary survey of the approach has been published elsewhere in brief form (**14**).

and of 'structure' as discrete entities in the living organism. Extending the concept of structure down to the infra-microscopic, it is assumed that functional cortical events are, essentially, structural events.

Since it is generally conceived that the brain functions as an integral unit, changes in one area, *A*, according to the concept of functional structuring, result in a change in the cortex as a whole (a functional restructuring). Thus, such a change should be detectable, with suitable instruments, in some other area, *B*. Since the electrocortical phenomena to be reported here are, probably, rather definitely occipital in origin (**2**), changes in other than the occipital region may be expected to influence the occipital alpha rhythm. It may, therefore, serve as a physiological indicator of the functional structuring of the whole cortex. The data to be reported later in this paper, as well as others (particularly Bakes', (**4**)), tend to substantiate this view.

Specifically, this investigation is concerned with the extension and verification of the two reports which have been reviewed, and with the experimental investigation of each of the two hypotheses which have been presented.

Apparatus and Procedure

The equipment used consisted of a three-stage resistance-capacitance-coupled amplifier (time constant, .67 sec.) and a special four-tube impedance-matching amplifier which drove a Boehm 2-A undulator (ink-writing oscillograph), modified to give reasonably faithful recording in the range of 0–28 cycles. The threshold sensitivity of the system was 5 microvolts. The recording tape was propelled at a constant rate of 40 mm per sec., providing direct reading of the record to the nearest .025 sec.

The subjects sat at a table in an electrostatically shielded semi-soundproof room (which was itself within a room adjacent to the recording room). Opposite the subject were two stimulus lights, each with an intensity (measured at the subject's eye) of .3 foot-candles. These lights were mounted in separate boxes, 12 inches apart in a horizontal plane, and were controlled by means of a relay which also acted as signal marker for the record. With reference to Fig. 1, when the magnet deflected upwards, one of the lights flashed on, and when the magnet returned to its original position, the light was extinguished. Selective control of either the right or the left light was possible by means of a switch.

The reaction-key used in the response experiments was in series with the relay during those experiments, so that the duration of the stimulus was then equal to the reaction time. In the control and other non-response experiments, the stimulus duration was from .3 to .6 sec. in duration, usually exceeding the latent time of blocking.

All records were taken with an active electrode high over the left occipital area and an inactive electrode on the lobe of the left ear. An ear-ring served as the inactive electrode, and a piece of flattened solder held in place by collodion as the active electrode. Commercial electrode paste interposed between scalp and electrode surface assured good contact.

Seven experiments were conducted, using a total of 15 adult subjects (14 male, 1 female). Experiment *A* was the verification experiment; experiments *B* and *C* were intended to check the first working hypothesis; and the other experiments were designed to check the second working hypothesis.

The procedures followed in each of the seven experiments are given below in detail:

A. Manual reaction to light (10 subjects, 9 male, 1 female):

1. Control run. Subjects instructed as follows:[5] "One or the other of these two lights will be flashed. Pay no particular attention to them."
2. Discriminatoy reaction. Subjects instructed as follows:[5] "Respond only to the right-hand light; do not respond to the left-hand light. Under these limitations, respond as fast as you can."
3. Speed reaction. Subject instructed as follows:[5] "Respond to either light, right-hand or left-hand; respond as fast as you can, regardless of which light is flashed on."

B. Subvocal reaction to light (4 male subjects):

1. Control run. Instructions as in control for *A*.
2. Discriminatory reaction. Subjects instructed as follows:[5] "Whenever the right-hand light is flashed it is to be counted, so that at the conclusion of the run you will know the exact number of times it has appeared. Do not count the times the left-hand light is flashed. Remember, get the total count of the number of times the right light is flashed."
3. Non-discriminatory reaction. Subjects instructed as follows:[5] "Count the total number of times any light is flashed on, left or right. When the run is concluded you should know the total number of times *a* light has been flashed."

C. Latent times measured with continuous 60 *db. tone sounding* (4 male subjects):

1. Control run.[6] Instructions as in control for *A*.
2. Test run. Instructions as for control. A continuous tone of 180 cycles (generating source a General Radio low-frequency oscillator working at maximum output, fed into loud speaker in experimental room).

D. Latent times measured with subject supporting ten pounds of weight (4 male subjects):

1. Control run.[6] Instructions as in control for *A*.
2. Test run. The subject here supported a five pound weight in each hand. The weights were placed on the palm of the hands, the arms supinated and resting on the table. At a verbal signal from the experimenter the forearms were raised to an angle of 45° with the surface of the table. A rest period in the middle of the run was decided on to avoid too great an effect from fatigue.

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[5] These exact words were not always used; they convey, however, the essence of the instructions.

[6] For purposes of economy, control runs for *C* and *D* were the same. The series was: Control, Tone, Weight.

E. Latent times measured with subject supporting weights of three magnitudes (4 male subjects):

1. Control run. Instructions as in control for *A*.
2, 3, and 4. Supporting 5, 10, and 20 pounds as in *D* 2.

F. Latent times measured with subjects supporting weights on feet, and on hands and feet (4 male subjects):

1. Control run. Instructions as in control for *A*.
2. Test run with foot board. Subject raised a board weighing 1¼ pounds on toes, heels acting as fulcrum.
3, 4, 5, and 6. As in 2, but with 5, 10, 15, and 20 pound weights on the board.
7. Five pounds divided between foot board and hands (as in *D* 2).
8, 9, and 10. As in 7, but with 10, 15, and 20 pounds divided.
11. Control run.

G. Latent times measured with subjects supporting weights of various magnitudes on hands, as in D, but with the weights increased in 5 pound steps. Each period was 5 minutes in duration, with 5 minute control periods between each weight-supporting period. In all, there were nine periods: control, 5 pounds, control, 10 pounds, control, 15 pounds, control, 20 pounds, control.

Analysis of Data

The data secured were analyzed quantitatively with respect to the latent time of blocking of the alpha rhythm. Latent time of blocking was defined as the time elapsing between the initiation of the stimulus and the moment of blocking of the alpha rhythm.

Blocking was defined as: (1) a complete depression of the alpha rhythm; or as (2) a relative depression of the alpha rhythm. Since a complete depression is clear-cut, no discussion of its characteristics need be gone into here. 'Relative depression,' however, is not an exactly definable term, and some discussion is necessary.

By 'relative depression' is meant: (1) any reduction in the amplitude of the alpha rhythm which exceeds the preceding amplitude by at least 50 percent, with the reduced waves continuing; (2) any reduction of at least 50 percent, followed by almost immediate resumption of the previous amplitude. Figure 1 will serve to illustrate 'complete depression' and 'relative depression' as the terms are here used.

The reliability of measurement of the latent times of blocking was determined by re-reading an unmarked record. On both readings the obtained mean was .31 sec., SD, .15 sec.,

although nine more presentations were judged effective on the second reading than on the first.

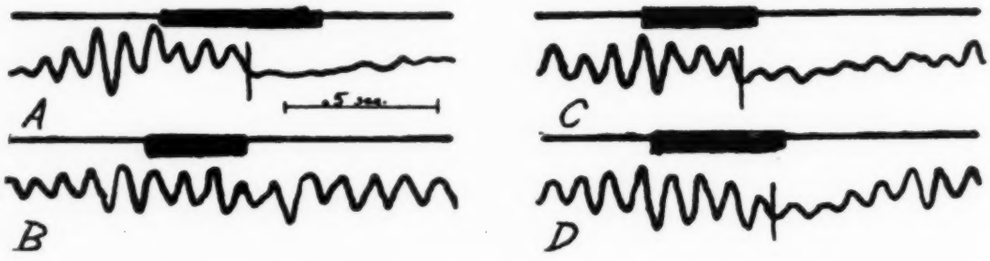

FIG. 1. Examples of electrocortical reactions to visual stimulation. *A*. 'Complete depression' of alpha rhythm. *B*. No observable change of alpha rhythm. *C, D*. 'Relative depression' of alpha rhythm. Solid block at top of record = stimulus. Time scale in *A* holds for all records.

RESULTS

In the presentation of the data it is not sufficient to present for the reader's inspection group means alone, and it will be noted that wherever practicable individual data are presented. This writer feels that in a field where subjects are generally few, and highly selected on the basis of their production of alpha waves, such individual presentation is essential. Group means may sometimes cover up individual variation, *i.e.*, two-thirds of a group may change in one direction, thus changing the mean, but the other one-third of the group may change in the opposite direction. On the other hand, individual variation may cover up group means, as is peculiarly evident in Experiment *G*, below.

A. Manual Reaction to Light.—The group data from the three experimental situations are presented in Table 1.

TABLE 1

MEAN LATENT TIME OF BLOCKING OF THE ALPHA RHYTHM OF THE CORTEX TO LIGHT (IN SEC.) UNDER CONDITIONS OF *No Response, Manual Discriminatory Response*, and *Manual Speed Response*

Experimental Condition	AM	SD	N
1. No response (control)	.27	.11	500
2. Response, discrimination between stimuli	.24	.07	553
3. Response, no discrimination, emphasis on speed	.21	.07	686

The mean reaction time in *2* was .53 ± .16 sec. (N = 493), and in *3*, .35 ± .03 sec. (N = 673).[7] The difference between the mean reaction times in 2 and 3 is statistically significant, the critical ratio (Diff./σ diff.) being 25.7.

When the mean latent times of blocking of the alpha rhythm are treated statistically to determine the significance of each difference, critical ratios of the following magnitudes obtain: $CR_{1-2} = 5.0$; $CR_{1-3} = 10.0$; $CR_{2-3} = 7.5$.

While the absolute magnitude of reduction in the experimental conditions may be expressed only in hundredths of a second, and may therefore appear to be insignificant, expression in terms of relative reduction gives a more tangible picture of what has taken place. Giving these expression as percentage reduction, it is found that *2* is 11 percent less than *1;* that *3* is 22 percent less than *1;* and that *3* is 12 percent less than *2*.

The individual data on the ten subjects are presented in Tables 2 and 3. These tables show the clear distinction between the three conditions studied. Nine of the ten subjects show a reduction from *1* to *3*, eight a reduction from *1* to *2*. Only one subject showed no reduction anywhere in the series.

It will be noted in Table 2 that a second condition of *no response* has been imposed on three of the subjects. This was done after the possibility suggested itself that the reduction was due to dark adaptation rather than to the conditions of the experiment. As is clear, the latent times observed in this second control period are of the same size as those of the initial control period. The mean obtained by lumping the data on the three subjects was .28 sec., SD, .11 sec. (N = 161).

This same possibility was tested in another manner by having one subject (BA) go through the experiment in reverse order (*3*, *2*, *1*, rather than *1*, *2*, *3*). In *3*, now temporarily first, the mean was .22 ± .09 sec. (N = 97); in *2*, .25 ± .08 sec. (N = 102); and in *1*, now temporarily third, .28 ± .12 sec. (N = 101). The critical ratios were: $CR_{1-2} = 2.1$; $CR_{2-3} = 2.5$; and $CR_{1-3} = 4.0$.

[7] Discrepancies with N in Table 1 are due to the fact that latent times were measured in response conditions even though no response was made.

TABLE 2

MEAN LATENT TIME OF BLOCKING OF THE ALPHA RHYTHM OF THE CORTEX (IN SEC.) FOR EACH SUBJECT OF THE MANUAL REACTION SERIES

Subject	No Response$_1$			Discriminatory Response			Speed Response			No Response$_2$		
	AM	SD	N	AM	SD	N	AM	SD	N	AM	SD	N
BA....	.31	.12	39	.24	.08	28	.23	.09	28			
BR....	.24	.10	37	.19	.07	28	.17	.04	19			
HA....	.30	.10	48	.21	.07	63	.21	.05	112	.30	.14	65
JO.....	.26	.09	56	.26	.11	74	.22	.07	90	.27	.09	41
KO....	.25	.07	64	.20	.05	66	.20	.04	98	.26	.07	55
KR....	.22	.09	80	.22	.04	130	.22	.04	145			
MI....	.29	.09	36	.29	.07	36	.24	.07	39			
TU....	.31	.11	39	.26	.08	45	.21	.08	88			
WH...	.28	.03	28	.25	.08	22	(.17)*	(.02)*	(9)*			
WY....	.30	.13	73	.26	.13	61	.25	.14	54			

* Due to the fact that WH had 'poor waves' during the reaction series, a sufficient sampling could not be obtained. These means and standard deviations are thus given parenthetically.

TABLE 3

SIGNIFICANCES OF DIFFERENCES IN MEAN LATENT TIME OF BLOCKING BETWEEN CONDITIONS OF *No Response* (NR), *Manual Discriminatory Response* (DR), AND *Manual Speed Response* (SR) FOR EACH SUBJECT

Subject	NR_1 vs. DR		NR_1 vs. SR		DR vs. SR		SR vs. NR_2	
	Diff. (sec.)	CR	Diff. (sec.)	CR	Diff. (sec.)	CR	Diff. (sec.)	CR
BA.....	.07	2.9	.08	3.1	.01	0.4		
BR.....	.05	2.4	.07	3.7	.02	1.3		
HA.....	.09	5.3	.09	6.0	.00	0.0	.09	5.0
JO.....	.00	0.0	.04	2.9	.04	2.7	.05	3.1
KO.....	.05	4.5	.05	5.0	.00	0.0	.06	6.0
KR.....	.00	0.0	.00	0.0	.00	0.0	.00	0.0
MI.....	.00	0.0	.05	2.6	.05	3.1		
TU.....	.05	2.4	.10	6.7	.05	2.5		
WH.....	.03	1.7	(.11)*	(12.2)*	(.08)*	(4.4)*		
WY.....	.04	1.7	.07	2.9	.03	1.2		

* Due to the fact that WH had 'poor waves' during the reaction series, a sufficient sampling could not be obtained in the speed response. Differences involving it are thus given parenthetically.

These two sets of measurements seem to rule out any temporal factor inherent in the experiment as being responsible for the observed data.

A reduction was found not only in the mean latent time of blocking but in the variability of the latent time of blocking. In the control period the SD was .11, while in the two response periods the SD was .07 sec. The differences are statistically significant, both critical ratios being 3.1. Jasper and Cruikshank also gave figures indicating such a reduction under conditions of response.

With the evidence at hand to reach the apparent conclusion that the faster the response the shorter the latent time of blocking (as might be inferred from Table 1), it seemed that the demonstration of this, if it was a correct conclusion, could be had by obtaining product-moment correlations between reaction time and latent time of blocking. Utilizing data on only those subjects where 50 or more pairs of measures were available, this was done. The results are given in Table 4.

TABLE 4

PRODUCT-MOMENT CORRELATIONS BETWEEN MANUAL REACTION TIME AND LATENT TIME OF BLOCKING OF THE ALPHA RHYTHM FOR SIX SUBJECTS

Subject	Discriminatory Set			Speed Set		
	r	PE	N	r	PE	N
BA*	.16	.07	97	.09	.07	95
HA	.00	.09	61	.05	.06	112
JO	.09	.07	71	.01	.07	90
KO	−.14	.07	59	−.06	.06	98
KR	−.25	.05	97	.19	.05	145
TU				−.01	.07	88

* Correlation data on BA are from the reverse-order control experiment referred to in text above.

From these correlations it seems apparent that there is no relationship between finger-reaction time and latent time of blocking of the alpha rhythm of the cortex as these two variables were measured in this experiment. Jasper and Cruikshank, however, have reported a product-moment correlation of .37 ± .09 (41 pairs of measurements) between these variables, under conditions similar to those of this experiment.

In order to bring further data to bear on this point the author has gone to the original data of Travis, Knott and Griffith. Utilizing 80 available pairs of measurements, secured from a total of six subjects, a product-moment correlation of .26 ± .07 was obtained between latent time of blocking and latent time of appearance of the muscle action potential in the extensor digitorum communis. Obviously no high correlation has been demonstrated.

While the relationship between manual reaction time and latent time of blocking is under consideration it is pertinent to examine the *gross* temporal relationship between initiation of overt response and the moment of blocking of the alpha rhythm. Jasper and Cruikshank state that the manual reaction never occurred before the blocking effect. Travis, Knott and Griffith, using the action current technique, to measure response, found that about one-third of 96 reactions occurred prior to the moment of blocking. In the experiments reported here it was found that the manual reaction could occur before the electrocortical reaction.

Specifically, in the discriminatory reactions (using 642 pairs of measurements): 2.2 percent showed the manual response occurring *before* the electrocortical reaction; .6 percent showed the manual reaction occurring *simultaneously* with the electrocortical reaction; and .2 percent (one pair) showed the manual reaction occurring *with no observable electrocortical reaction.*

In the speed reaction (using 796 pairs of measurements): 9.2 percent showed the manual reaction occurring *before* the electrocortical reaction; 1.3 percent showed the manual reaction occurring *simultaneously* with the electrocortical reaction; and in no instance did a manual reaction occur with no correlated electrocortical reaction.

From these data it would seem that there is not any necessary relationship between the latent time of blocking of the alpha rhythm of the cortex and manual reaction time. Certainly, blocking is not an index of any cortical process propedeutic to response.

B. Subvocal Reaction to Light.—Experiment *B* was designed as a delimiting experiment to rule out the influence of the gross manual reaction, made in *A*, on the latent times. In these experiments there was a predetermined response, but it was covert, not overt. The individual and group data are presented in Table 5.

TABLE 5

MEAN LATENT TIME OF BLOCKING OF THE ALPHA RHYTHM OF THE CORTEX (IN SEC.) FOR 4 SUBJECTS IN A CONDITION OF *No Response*, *Discriminatory (Sub-vocal) Response*, AND *Non-discriminatory (Sub-vocal) Response*

Subject	Control			Count Right Light			Count Both Lights		
	AM	SD	N	AM	SD	N	AM	SD	N
JO.....	.27	.09	70	.26	.08	71	.23	.09	65
KO.....	.24	.07	119	.22	.09	84	.21	.06	89
HA.....	.23	.06	53	.21	.07	54	.23	.06	39
TU.....	.27	.09	82	.25	.09	55	.24	.08	61
All four.	.25	.08	324	.23	.08	264	.23	.08	254

The reduction here was not expected unless there was some common element which also operated in *A*. This common element could be: (1) 'mental set' as a central process, independent of any peripheral factors beyond the initial instructions; or, (2) 'mental set' as a peripheral process, the result of the instructions; or, (3) implicit muscular response following each stimulation.

Since the observed differences (see Table 6) between the 'response' and 'control' run were of statistical significance and since the relative magnitude of the reduction was ap-

TABLE 6

SIGNIFICANCES OF DIFFERENCES IN LATENT TIMES OF BLOCKING DURING CONDITIONS OF *No Response* AND *Sub-vocal Responses* FOR 4 SUBJECTS

Subject	Control vs. 'Count Right'		Control vs. 'Count Both'		'Count Right' vs. 'Count Both'	
	Diff.	CR	Diff.	CR	Diff.	CR
JO.....	.01	0.7	.04	2.5	.03	2.0
KO.....	.02	1.7	.03	3.3	.01	0.8
HA.....	.02	1.5	.00	0.0	.02	1.4
TU.....	.02	1.3	.03	2.1	.01	0.6
All four.....	.02	2.9	.02	2.9	.00	0.0

preciable (8 percent in both instances) it seemed clear that factors were operating which need be isolated before the fundamental problem of this research could be answered, especially in view of the fact that the subjects reported muscular tension during the experimental runs.

C. Latent Times Measured with Continuous Auditory Stimulation.—This experiment was designed with the hope of setting up in the cortex a consistent pattern, different from that obtained as a result of proprioceptive stimulation. The data are presented in Table 7 with the data from *D*. The difference between the control data and the stimulus data approach statistical significance (there are 997 chances in 1000 that the difference is a true difference greater than zero) and the relative magnitude of the reduction is 8 percent.

The data, however, were vitiated from the standpoint of the original purpose of the experiment, for all the subjects reported considerable muscular tension during the prolonged stimulation with the pure tone.

D. Latent Times Measured with Subject Supporting Ten Pounds of Weight (five pounds in each hand).—In this experiment it appeared safe to assume that the factor under examination would be peripheral stimulation via the proprioceptive tracts. Muscular strain was set up in a thorough and continuous manner. The data (with those of *C*) are presented in Table 7.

TABLE 7

MEAN LATENT TIME OF BLOCKING OF THE ALPHA RHYTHM OF THE CORTEX (IN SEC.) FOR FOUR SUBJECTS IN A CONDITION OF *No Stimulation*, *Continuous Auditory Stimulation* AND *Continuous Proprioceptive Stimulation*

Subject	Control Period			Auditory Stimulus Period			Proprioceptive Stimulus Period		
	AM	SD	N	AM	SD	N	AM	SD	N
JO.....	.26	.07	67	.23	.07	86	.22	.07	88
KO.....	.23	.07	84	.22	.05	76	.20	.04	57
HA.....	.29	.09	59	.27	.12	88	.26	.11	93
TU.....	.26	.08	30	.25	.08	47	.20	.06	50
All four.	.26	.08	240	.24	.09	297	.23	.09	288

The reduction in mean latent time associated with the support of the ten pounds of weight is statistically significant (see Table 8), and the relative magnitude of reduction was 12 percent.

TABLE 8

SIGNIFICANCES OF DIFFERENCES IN MEAN LATENT TIME OF BLOCKING BETWEEN A CONDITION OF NO STIMULATION AND CONDITIONS OF AUDITORY AND PROPRIOCEPTIVE STIMULATION

Subject	Control vs. Auditory			Control vs. Proprioceptive		
	Diff. (sec.)	CR	Chances in 1000	Diff. (sec.)	CR	Chances in 1000
JO.....	.03	2.7	997	.04	3.6	999.7
KO.....	.01	1.0	840	.03	3.3	999
HA.....	.02	1.2	880	.03	1.9	970
TU.....	.01	0.5	690	.06	3.5	999.5
All four.....	.02	2.7	997	.03	4.1	999.9

E. Latent Times Measured with Subject Supporting Weights of Three Magnitudes.—Since the data secured in *D* had indicated that the supporting of ten pounds of weight could reduce the latent time of blocking of the alpha rhythm by 12 percent, it seemed essential to determine whether or not there was a relationship between the amount of weight and the magnitude of reduction of the latent time. Accordingly, weights of five, ten, and twenty pounds were selected. The data are presented in Table 9, and the statistical comparisons

TABLE 9

MEAN LATENT TIME OF BLOCKING OF THE ALPHA RHYTHM OF THE CORTEX (IN SEC.) FOR FOUR SUBJECTS IN A CONDITION OF *No Stimulation*, AND CONTINUOUS PROPRIOCEPTIVE STIMULATION OCCURRING WITH THE SUPPORT OF *Five Pounds*, *Ten Pounds*, AND *Twenty Pounds Weight*

Subject	Control Period			Five Pound Stimulus Period			Ten Pound Stimulus Period			Twenty Pound Stimulus Period		
	AM	SD	N	AM	SD	N	AM	SD	N	AM	SD	N
JO.....	.29	.09	93	.28	.08	57	.24	.08	52	.26	.09	77
HA.....	.29	.10	58	.26	.08	65	.26	.09	53	.25	.07	44
TU.....	.23	.08	60	.19	.08	68	.20	.07	89	.20	.07	72
KO.....	.21	.07	37	.21	.07	34	.18	.06	39	.19	.07	33
All four..	.26	.09	248	.24	.09	224	.22	.08	233	.23	.08	226

are presented in Table 10. The relative magnitudes of reduction are: control to 5 pounds, 7 percent; control to 10 pounds, 15 percent; and control to 20 pounds, 11 percent.

TABLE 10

SIGNIFICANCES OF DIFFERENCES IN MEAN LATENT TIME OF BLOCKING BETWEEN CONTROL AND THREE WEIGHT-SUPPORTING PERIODS

Subject	Control vs. Five Pounds		Control vs. Ten Pounds		Control vs. Twenty Pounds	
	Diff.	CR	Diff.	CR	Diff.	CR
JO	.01	0.7	.05	3.6	.03	2.1
HA	.03	1.9	.03	1.7	.04	2.4
TU	.04	2.9	.03	2.3	.03	2.3
KO	.00	0.0	.03	2.0	.02	1.2
All four	.02	2.5	.04	5.0	.03	3.8

From these data one would be led to the conclusion that ten pounds gave the maximum effect, and that above that stimulus value there was some falling off of the effectiveness of the stimulus.

F. Latent Times Measured with Subject Supporting Weights of Four Magnitudes on Feet, and on Feet and Hands.—This rather peculiar experiment was conducted to discover whether or not data comparable to those obtained in *E* would be obtained by stimulation over different proprioceptive tracts, and whether or not proprioceptive impulses arriving in two parts of the cortex would be more effective than those arising in one. On the whole, this experiment was negative. Table 11 presents results obtained from the three subjects; it is obvious that in this instance weight had no effect on the latent time of blocking. The reasons for this are unknown, but fatigue factors might be suggested as a possible, but tentative, explanation. In no other experiment was it found, consistently, that weight was ineffective in reducing the latent time of blocking.

G. Five Pound Increment Series with Control Runs between Each Weight-Supporting Period.—Nine male subjects were used in this series, which was set up in an attempt to eliminate the unknown, but possibly fatigue, factors which were operat-

TABLE 11

MEAN LATENT TIME OF BLOCKING OF THE ALPHA RHYTHM OF THE CORTEX (IN SEC.) FOR THREE SUBJECTS DURING SUPPORT OF VARIOUS WEIGHTS BY FEET AND FEET AND ARMS

	KO			TU			HA			Group		
	AM	SD	N	AM	SD	N	AM	SD	N	AM	SD	N
$Control_1$	.21	.08	68	.24	.09	60	.31	.15	98	.26	.12	226
Board only on feet	.20	.07	55	.22	.10	53	.27	.13	80	.23	.11	188
5 lbs. and board on feet	.20	.08	51	.25	.11	50	.28	.14	51	.25	.12	52
10 lbs. and board on feet	.23	.07	60	.24	.11	50	.29	.12	73	.26	.11	183
15 lbs. and board on feet	.22	.09	62	.24	.10	52	.30	.13	51	.25	.10	165
20 lbs. and board on feet	.25	.08	55	.22	.07	53	.28	.12	60	.29	.09	168
5 lbs. on hands and feet	.23	.10	63	.25	.11	58	.30	.12	57	.26	.11	178
10 lbs. on hands and feet	.24	.08	60	.23	.10	56	.27	.12	57	.24	.10	173
15 lbs. on hands and feet	.23	.09	62	.24	.10	53	.32	.13	59	.26	.12	174
20 lbs. on hands and feet	.22	.08	50	.23	.10	50	.26	.12	74	.24	.10	174
$Control_2$	.24	.08	47	.23	.08	69	.32	.12	65	.27	.10	181

ing to produce negative data in *F*. Each weight supporting period in this series was five minutes in duration, with a period of equal duration between each in which the subject sat relaxed for control measurements. Starting with five pounds of weight, they worked up to twenty pounds of weight.

The group data, presented in Table 12, obviously have no significant differences among them, when any control period is compared with its just preceding or just succeeding weight

TABLE 12

MEAN LATENT TIME OF BLOCKING DURING WEIGHT-SUPPORTING AND REST PERIODS, EXPERIMENT *G*

	AM (sec.)	SD (sec.)	N	Significances of Differences	
				Diff. (from just preceding)	CR (with just preceding)
C_1	.29	.11	743		
Five Pounds	.30	.11	693	−.01	1.8
C_2	.31	.11	635	−.01	1.7
Ten Pounds	.29	.11	607	.02	3.2
C_3	.30	.11	549	−.01	1.5
Fifteen Pounds	.29	.10	648	.01	1.6
C_4	.30	.12	483	−.01	1.5
Twenty Pounds	.29	.11	636	.01	1.4
C_5	.30	.11	632	−.01	1.6

period, except that difference obtaining between C_2 and 10 pounds.

In order to discover whether or not each subject gave data of the same order as these group data, a table of individual means was constructed. It was found from this table that 6 of the 9 individuals showed, with reasonable consistency, a shorter latent time of blocking during the weight periods than during the control periods, and these six gave consistently high critical ratios in this direction, while the others gave low critical ratios in the opposite direction. Consequently the group of 9 was divided into a 'weight-effective group' and a 'weight-ineffective group.' The means for these two groups, as well as the statistical significances of the differences between each period and its just preceding period, are given in Table 13. In the 'weight-effective group' only

TABLE 13

MEAN LATENT TIME OF BLOCKING IN WEIGHT AND REST PERIODS FOR THE WEIGHT-EFFECTIVE GROUP AND THE WEIGHT-INEFFECTIVE GROUP

	Effective Group (6)					Ineffective Group (3)				
	AM	SD	N	Diff. from just preceding	CR with just preceding	AM	SD	N	Diff. from just preceding	CR with just preceding
C_1	.30	.10	541			.30	.11	202		
Five pounds	.29	.11	455	.01	1.4	.31	.10	238	.01	1.0
C_2	.31	.11	407	.02	2.5	.30	.11	228	.01	1.0
Ten pounds	.29	.11	386	.02	2.5	.29	.11	221	.01	1.0
C_3	.31	.11	376	.02	2.5	.29	.10	173	.00	0.0
Fifteen pounds	.28	.10	435	.03	4.3	.31	.11	213	.02	1.4
C_4	.30	.11	370	.02	2.9	.29	.12	113	.02	1.4
Twenty pounds	.28	.11	403	.02	2.5	.31	.11	233	.02	1.5
C_5	.30	.11	436	.02	2.5	.29	.11	196	.02	1.8

one critical ratio below 2.5 was found, when any control period was compared with its following weight period, while in the 'weight-ineffective group' the highest critical ratios were 1.8, and these were in the opposite direction.

Figures 2 and 3 show, in graphic form, the mean latent times of blocking for each individual in each of the two groups. These graphs demonstrate the individual data more clearly, as well as more concisely, than could a table.

In the 'weight-effective group' it seems clear that increased proprioceptive stimulation is adequate to reduce the latent time of blocking. In the 'weight-ineffective group'

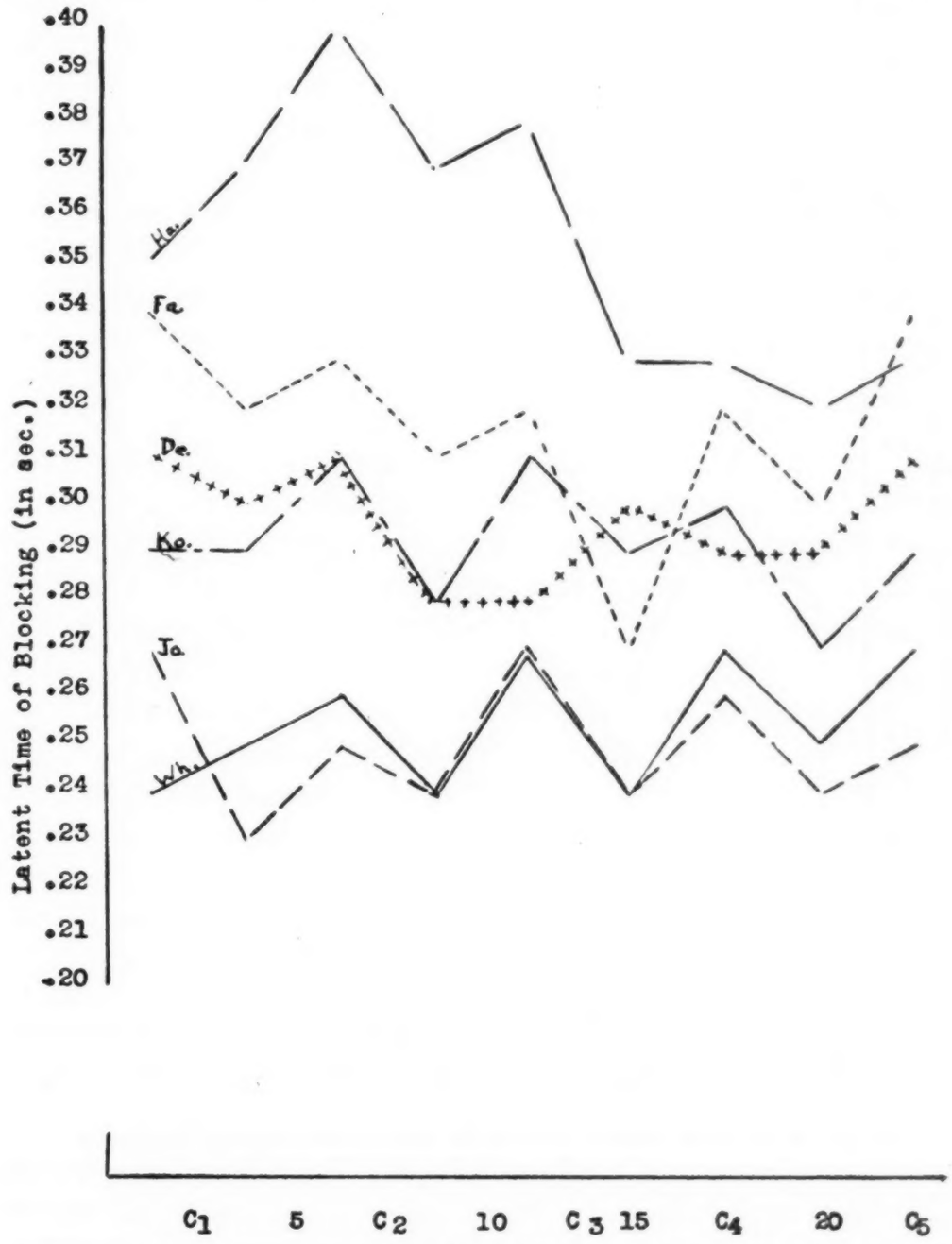

FIG. 2. Mean latent time of blocking for each of the 6 'weight-effective' subjects in Exp. *G*. C_2, etc. = control (rest) periods. 5, 10, etc. = magnitude of supported weight.

the converse is not true, *i.e.*, increased proprioceptive stimulation is adequate to increase the latent time of blocking; but it is perfectly clear that for some reason it is not reducing it.

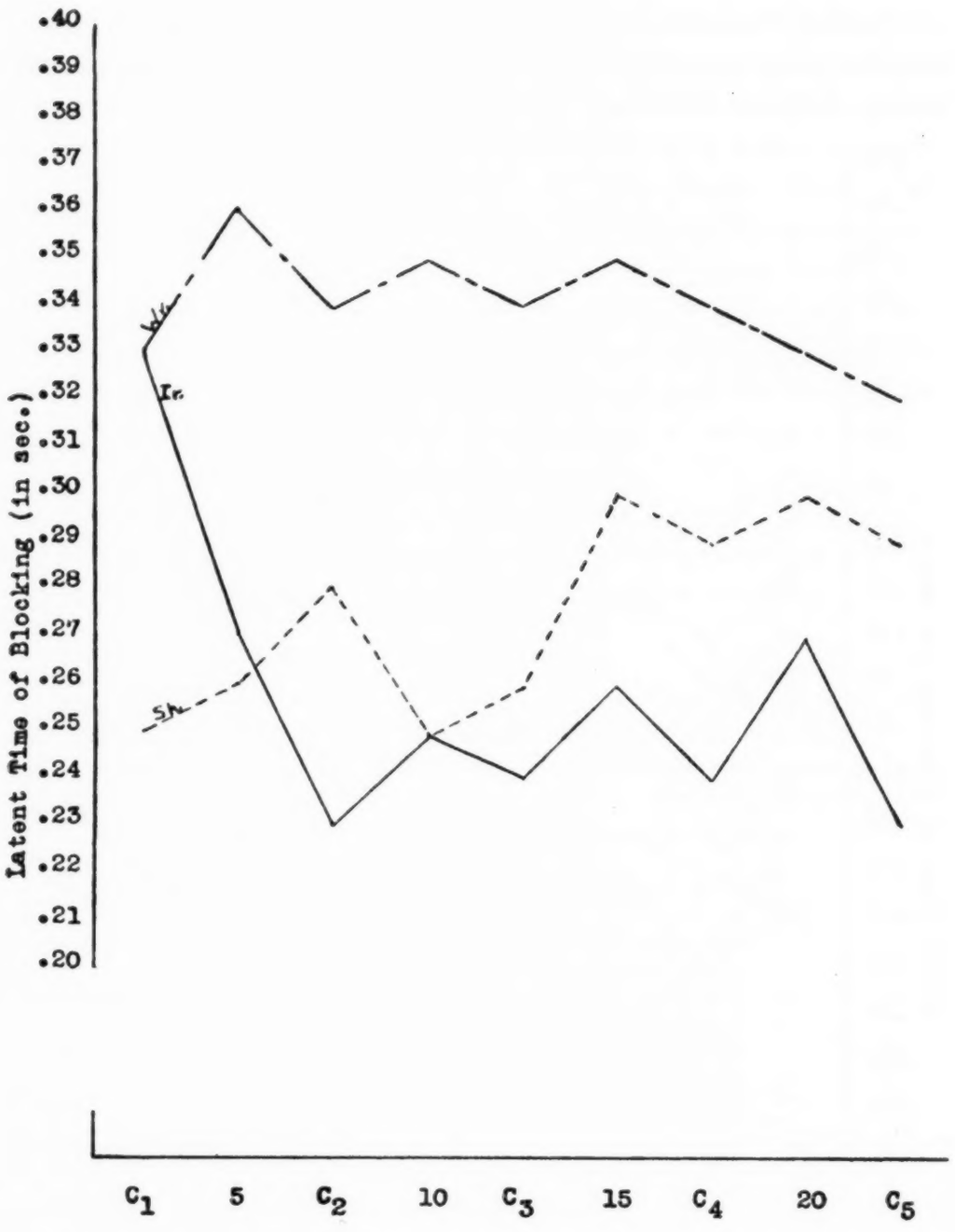

FIG. 3. Mean latent time of blocking for each of the 3 'weight-ineffective' subjects in Exp. *G*.

DISCUSSION

At the outset of this investigation it was suggested that either of two sets of factors might be responsible for data relating 'mental set' to the electrocortical phenomenon of reduced latent time of blocking of the alpha rhythm to light.

The first of these attributed the reduction to peripheral factors, the second attributed the reduction to central factors.

The dichotomy, as stated, is a direct outgrowth of Freeman's (**8**) discussion of 'set.' In a sense, this is a verbal rather than a factual dichotomy; for, in fact, it would be impossible to draw any clear line of demarcation between the two 'factors.' The peripheral phenomena to which the reduction in latent time of blocking may be attributed are, in the last analysis, themselves the result of central (motor) phenomena. However, the peripheral hypothesis set up here would attribute the reduction to centripetal impulses rather than centrifugal impulses; or, to a sensory rather than to a motor gradient.

The various experiments reported above lead to the conclusion that the reduction in mean latent time of blocking is peripherally determined. In all of the experiments, except Experiment *F*, increased kinesthesis led to such a reduction, although it was, relatively, never as great as that obtained in the 'speed set' of this report (22 percent) or the 'prepared response' of Jasper and Cruikshank (28 percent).

In those experiments involving an overt response to the stimulus it was found that the variability of the latent time of blocking was also reduced. This was true not only for the group as a whole, but for the majority of the individual subjects. This phenomenon was not observed by Travis, Knott and Griffith, but it was indicated in the published data of Jasper and Cruikshank. Decrease in variability was not observed in the data from covert response and non-response experiments.

Both phenomena may be 'explained' by hypothecating a shift in the organization of cortical precesses (functional restructuring) during the overt response series as opposed to the control series. Assuming that other cortical areas (and subcortical areas) than the occipital area (the one here studied) have an effect on the occipital area, it is a reasonable further supposition that when these other areas randomly vary in their own activity they randomly affect the occipital area. Still further, when some condition exists which could alter the

activity of these other areas, their effects on the occipital area would likewise be altered.

The peripheral (proprioceptive) factors alter certain of these conditions, and this appears as decreased latent time of blocking. This may be the end-result of an increase in the susceptibility of the occipital area to the optic nerve impulse which is attendant upon an increase in activity in some other area. From the control experiments, this seems reasonable.

Since reduced variability was never observed in the control experiments, a central factor is posited as that responsible for the decreased variability. This decreased variability may be the end-result of a stabilization of the activity of the other (than occipital) areas which is attendant upon the instructions given the subject and the constant 'set' *in the direction of* the response.

This hypothesis is offered for confirmation. The fact that decreased variability was not observed in the covert response experiment may weaken it; or it may suggest that a sufficient sensory substrate (kinesthesis) is necessary before the phenomenon may be observed. In any event, it can be stated that decreased mean time and decreased variability are independent, for in the manual discriminatory response experiment (*A*) both were observed, while in the first weight-supporting experiment (*D*) only the former was observed; the reductions in mean time were 11 and 12 percent, respectively.

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EFFECT OF RESPONSE TO AUDITORY STIMULATION ON THE LATENT TIME OF BLOCKING OF THE BERGER RHYTHM *

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Introduction

Psychologists have shown an increasing interest in electroencephalography as a new approach to the understanding of the problems of mental life. This technique lends itself rather well to an investigation of the neurophysiological correlates of certain psychological phenomena.

One of the most frequently investigated brain potential phenomena is that of the effects produced upon the Berger rhythm by various types of stimulation. Regardless of whether one believes that the alpha rhythm arises from the occipital part of the brain (Adrian (1)) or that it has a wider and less specific origin (Berger (3)), the most commonly reported observation is that vision is the most effective of all the sensory modalities in disturbing or changing it. Many laboratories have studied the depression of the rhythm, measuring their observations in terms of the delay following sensory stimulation before the potentials were depressed or dropped out (latent time of blocking), period of time required for the normal rhythm to be reestablished (perseveration or recovery time), and the degree of effectiveness which the stimulus displays. Berger (3) reported latencies from .09 to .70 sec. for various types of stimulation, such as tactual, visual, and auditory. He found latent time for sound to be .42 sec. Travis, Knott, and Griffith (8) reported a mean latency of .28 sec. to light in a passive stimulation situation,

* Condensed Ph.D. thesis, State University of Iowa, June, 1938. Study done under direction of Professor Lee Edward Travis.

this value dropping to .24 sec. when the subject was required to respond to the visual stimulus by moving his right arm.

Light appears to be about 95 to 100 percent effective in depressing the alpha rhythm. Travis and Egan (7) reported it to be 99 percent effective. Auditory stimulation has been employed less frequently than visual in brain potential studies because it has yielded less promising observable results. Bagchi (2) reported that meaningful words would affect the alpha rhythm about 36 percent of the time. Jasper and Cruikshank (4) found that by using a weak sound stimulus as a preparatory signal before presenting a light stimulation, it was difficult to determine the role of 'set' in cortical reaction to light, because "the disappearance of the alpha rhythm is readily associated with other forms of stimulation (sound) and may even be conditioned to stimuli to which there was no unconditioned response." Loomis, Harvey and Hobart (6) state that a low tone can be conditioned to light in its effect upon the Berger rhythm, but they offer no statistical data. Travis and Egan (7) conditioned the electrical response of the cortex to a pure tone of 180 d.v. by presenting the tone with light, raising the effectiveness of sound from 11 percent in a pre-conditioning passive situation (tone alone) to 35 percent when associated with light.

These observations on the comparative effectiveness of light and sound as stimuli indicate that light possesses some property in and of itself to alter brain potential pattern and therefore tone, which apparently does not, at least to such a degree, would offer more possibilities to study associated psychological phenomena in relation to brain potentials. This line of thought offered a point of departure for making the present study.

Problem

It was the purpose of the present study to investigate the effect upon the latent time of blocking of the brain rhythm when the subject is required to respond to auditory stimulation. Knott (5) has shown that the latency of cortical response to light, under normal passive conditions, can be reduced significantly when the subject is placed in various experimental situations requiring neuromuscular 'set' and motor response. In one of his response situations, the subject made a manual discriminatory response to the presentation of a 'right' and a 'left' light, while in another experiment

he made a manual 'speed' response to both lights. Knott found, in part, that the latencies became progressively shorter from control (non-response), through discriminatory response to speed response conditions. He also found that the variability of the latent time of blocking was less in any response situation than in a non-response one. The present study parallels that of Knott in some of its aspects, in that it attempts to investigate latent time of blocking under response conditions in the auditory sense field which he observed in the visual. Other phases of the study were concerned with effectiveness and the relationship between latent and reaction times.

Apparatus and Procedure.—In recording the brain potentials, standard amplifier equipment, previously described (8) was used to drive a Boehm 2-A undulator (ink-writing), modified to increase the frequency range to 28 cycles per sec. Surface electrodes were used, one being attached to the head over the left occipital area and the other one to the lobe of the left ear.

One of the first problems was to find an auditory stimulus which could be well defined and controlled, and which would be sufficiently effective in blocking out the Berger rhythm to enable us to measure possible changes in latent time. It was found that by using two pure tones of different frequencies, our purpose was served adequately.

The subject was presented a random series of high and low tones, of 250 d.v. and 120 d.v., respectively. The high tone was produced by a General Radio Type 377-B Audio Frequency Oscillator and the low tone by a General Radio No. 613-B Beat Frequency Oscillator. The tones, which were of medium intensity, were judged to be of equal loudness by four individuals, recording their judgments independently, but simultaneously.

The subject was placed in a semi-soundproofed, electrostatically shielded, dark room and received the auditory stimulations through a dynamic speaker mounted in the wall above and in front of him. He was instructed to sit at a table with his eyes open. The purpose of this procedure was to make our conditions comparable to those used by Knott (5) in a similar experiment employing visual stimulations. The experimenter attempted to present the tones at times when the alpha rhythm was 'in' for the subject. The duration of the stimulus was approximately .65 sec., excepting, of course, in the response situations, in which the duration was determined by the reaction time of the subject.

In the first control situation the subject was instructed to assume a comfortable position, attempt to relax and to avoid making any bodily movements after the experiment was started. He was then presented a series of from 100 to 140 high and low tones, in random order. This was a passive, non-response situation.

The first experimental situation followed after a brief rest period. For this series, the instructions for S were somewhat the same as in the control, excepting that he was to respond by pressing a key whenever, and as soon as, he heard the high tone. He was cautioned against responding to the low tone. Another brief rest period was permitted. This situation will be referred to as a discriminatory response condition.

In the third part of the experiment, S was instructed to respond 'as fast as he could' to both high and low tones. Here the emphasis was placed upon *speed* of response, with no discriminations involved. This experimental situation will be referred to as a speed response condition.

Following the customary rest period, the second control series was presented. The instructions at this time were exactly the same as those in the first control situation. Approximately the same number of stimulations was presented in each series.

Results

From eight adult subjects a total of 2914 readable records were obtained. Of these records, 1480 resulted from high tone and 1434 from low tone stimulation. Those records showing the following characteristics were discarded as unreadable: (1) the alpha waves were absent at the instant of tonal stimulation; (2) they disappeared simultaneously with the presentation of the stimulus; and (3) they disappeared too quickly (.05 sec.) after the tone to give a valid latency.

The records were evaluated in terms of three quantitative measurements: effectiveness, latency, and reaction time. By effectiveness is meant an obliteration or a striking depression of the alpha rhythm related to the onset and duration of the stimulus. Latency is the temporal interval between the instant of appearance of the stimulus and the obliteration or striking depression of the cortical potentials. Reaction time is the temporal interval between the instant of appearance of the stimulus and the manual response (key-pressing).

Effectiveness.—The results reported in Table I indicate the following trends: (1) the high and low tones were equally

TABLE I

Relative Effectiveness of High and Low Tones in Blocking Out the Alpha Rhythm under Control and Experimental Conditions for all Subjects

	Control 1		Discriminatory Response		Speed Response		Control 2	
	H	L	H	L	H	L	H	L
Percentage.....	35.1	33.5	62.5	40.1	40.9	48.1	27.1	27.9

effective in blocking out the Berger rhythm in both control situations; (2) responding to the high tone only resulted in a significant increase in effectiveness for it but only a slight increase in effectiveness for the low tone; (3) the effectiveness for high and for low tones became more nearly equal again under conditions in which S is responding to both (speed response); (4) the effectiveness under the second experimental conditions was lower than it was in the discriminatory response

situation; (5) the effectiveness for both high and low tones was lowest in the second control situation.

Viewing all of the possible inter-relationships between the high and low tones, in regard to effectiveness, we find that the least differences were between the two tones in any one situation excepting discriminatory response. Responding to the high tone resulted in a significantly greater difference in effectiveness between the two tones than was found in either control or speed response situations. This difference is 14 times as great as in the first control, 28 times as great as in the second control, and 3.1 times as great as in the speed response situation. The significance of some of these differences is shown in Table II.

TABLE II

SIGNIFICANCE OF THE DIFFERENCES BETWEEN THE PERCENTAGES OF EFFECTIVENESS TO HIGH AND LOW TONES, FOR ALL SUBJECTS, UNDER CERTAIN CONTROL AND RESPONSE CONDITIONS

(The tone having the greater percentage of effectiveness is always listed first)

Experimental Situation	Diff.	CR
Discriminatory Response (High tone) *vs.* Control 1 (High tone)	27.4	5.1
Discriminatory Response (High) *vs.* Speed Response (High)	21.6	4.0
Discriminatory Response (High) *vs.* Control 2 (High)	35.4	6.2
Discriminatory Response (High) *vs.* Discriminatory Response (Low)	22.4	4.0
Speed Response (Low) *vs.* Control 1 (Low)	14.6	2.6
Speed Response (Low) *vs.* Control 2 (Low)	20.2	3.6

Note: No CR's were computed on the differences between high and low tones within a given situation, excepting Discriminatory Response, since none of these differences exceeded 8 percent.

Figure 1 presents graphically the data discussed above, showing also the relationship between effectiveness and latent time of blocking of the Berger rhythm.

Latent Time of Blocking.—The latencies reported in Table III show a definite trend in the direction of becoming shorter

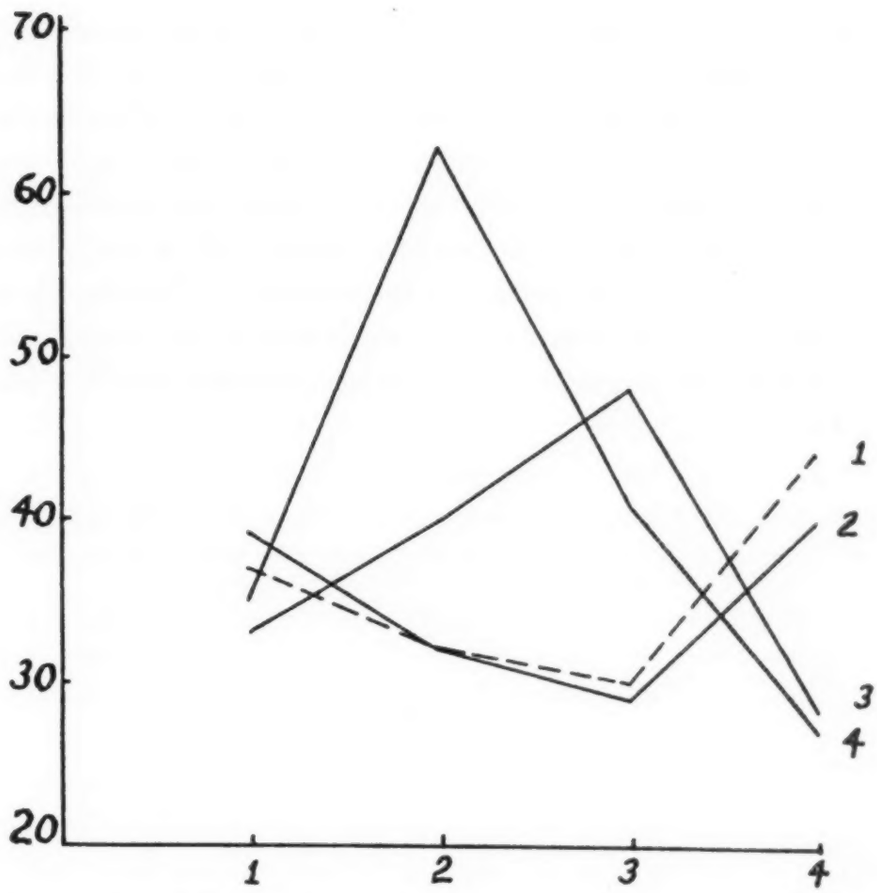

FIG. 1. Graph showing trends of mean latencies and percentage of effectiveness in all experimental conditions. The ordinate scale may be read as mean latent time of blocking in hundredths of a second or as percentage of effectiveness. The abscissa gives the experimental situations, in temporal order from left to right, as follows: 1 = control one, non-response; 2 = discriminatory response, manual response to high tone only; 3 = speed response to both high and low tones; 4 = control two, non-response. Curve 1 = mean latencies for low tone stimulus; curve 2 = mean latencies for high tone stimulus; curve 3 = percentage of effectiveness for low tone; curve 4 = percentage of effectiveness for high tone.

TABLE III

MEAN LATENCIES AND STANDARD DEVIATIONS FOR ALL SUBJECTS UNDER CONTROL AND EXPERIMENTAL CONDITIONS

Experimental Situation	Mean	S.D.	N
Control 1			
High	.39	.22	134
Low	.37	.23	131
Discriminatory Response			
High	.32	.09	198
Low	.32	.17	124
Speed Response			
High	.29	.13	152
Low	.30	.14	169
Control 2			
High	.40	.23	111
Low	.44	.27	107

in both response situations, following an initial passive, non-response condition. In the post-response control, the latent times return to an ever greater length. The magnitude of reduction in mean latency from the first control to the discriminatory response situation is 16 percent, while the magnitude of increase in mean latency from the discriminatory response to the second control is 23 percent. The significance of the differences between the mean latent times and between the standard deviations of the distributions are shown in Table IV.

TABLE IV

SIGNIFICANCE OF THE DIFFERENCES BETWEEN THE MEAN LATENCIES AND BETWEEN THE STANDARD DEVIATIONS OF THE DISTRIBUTIONS, FOR ALL SUBJECTS, IN CERTAIN CONTROL AND RESPONSE SITUATIONS

(The situation or tone having the longer latent time is always listed first)

Experimental Situations	CR (Mean)	CR (S.D.)
Control 1 *vs.* Discriminatory Response	3.3	8.5
Control 1 *vs.* Speed Response	4.8	8.2
Control 2 *vs.* Discriminatory Response	4.9	10.6
Control 2 *vs.* Speed Response	6.2	10.2
Control 1 (High tone) *vs.* Control 1 (Low tone)	.53	.08
Control 2 (High tone) *vs.* Control 2 (Low tone)	1.08	1.77

Note: High and low tones are combined, since their mean latencies did not vary more than .04 sec. within a given situation, excepting in the last two pairs.

It will be observed that the mean latency of the cortical response to the high tone is approximately equal to that of the low tone under every experimental condition studied. The largest difference between the two tones in any given experimental situation is .04 sec. (CR = 1.77), which indicates that none of the differences between the high and low tones are significant. It is interesting to observe here that in the discriminatory response situation, the mean latencies in response to the high and low tones were almost identical,

regardless of the fact that S was responding to the high tone only. We may conclude from these data that the pitch of the tonal stimulations used in this study is not an important factor, in and of itself.

Although the standard deviations of the mean latencies in the two control series show a rather wide range, they indicate definite trends when compared with the standard deviations of the latencies in the two response situations (Table IV). Making a manual response to the auditory stimulus not only reduces the mean latent time of blocking of the Berger rhythm, but also reduces the variability of the latencies measured.

The trend of the mean latencies discussed in this section and the relationship between latent time of blocking and effectiveness is presented graphically in Fig. 1.

Reaction Time.—It will be recalled that the subject was required to respond by pressing a key whenever he heard the high tone in the first, and to respond to both high and low tones in the second, experimental situation. The mean reaction time for all subjects was .45 sec. in the first and .29 sec. in the second response situation. The magnitude of this reduction is 35 percent. In the latter situation, mean reaction time was almost identical for high and low tones.

These findings are about as one might expect, for we are dealing here with nothing more than traditional reaction time phenomena. Our 'speed response to both stimuli' is a simple muscular reaction, with the attention focused on the motor component. This naturally yields a shorter reaction time than the discriminatory response does, since in the latter, the situation is more complex and results in an additional delay.

In the discussion which follows later, an attempt shall be made to show the extent of relationship between, or independence of, reaction time to latent time of blocking of the Berger rhythm and to the effectiveness of tonal stimulation in depressing the rhythm.

Reaction Time and Latent Time of Blocking.—The product moment correlations between manual reaction time and

latent time of blocking of the alpha rhythm were .60 ± .03 (N = 195) and .17 ± .04 (N = 319) for the discriminatory and the speed sets, respectively. These coefficients, particularly the first, are higher than those reported by Knott (**5**). A possible explanation of this is that in Knott's experiments light was the stimulus employed, while in these, tone was the stimulus employed. Light being more effective than tone, the distribution of latent times was limited. In the experiments involving tonal stimulation, however, there was no such limitation imposed.

Qualitative Evaluation.—Examination of the brain wave records revealed altered patterns and shifting characteristics of the wave form under the various experimental conditions studied. An increase in irregularity of the waves was observed in the two response situations, with a return to the normal characteristic alpha rhythm in the second control.

One might postulate that instructions and response introduce 'mental' factors which cause a shifting of focus, and at times an obliteration of the Berger rhythm. Perhaps a simpler explanation is that in the performance of a muscular response there is an increase in tension not only in the muscles involved in the response, but also in the entire body.

Discussion

In the three measures studied, effectiveness, latent time and reaction time, no significant differences were found between high and low tonal stimulations, excepting in the effectiveness of the two tones in the discriminatory response situation. This fact will facilitate a discussion of the various trends observed without specific reference to either high or low tones, with the one exception just noted.

Our results suggest some basic cortical relationship between effectiveness, reaction time and latent time of blocking of the Berger rhythm in response to auditory stimulation under certain conditions of 'mental set.' Careful analysis of our data indicates, however, that the nature and extent of these relationships are very difficult to postulate. One can see at once that reaction time is longest and tone is most

effective in disturbing the potential rhythm under the condition of discriminatory response to the stimulus. Likewise, reaction time is shorter and effectiveness is less in a simple muscular response situation. We have already stated that reaction time is usually found to be longer in a discriminatory response because of the increased cortical delay imposed upon the stimulus-response arc by the task of discrimination. Could it be then, that the psychological factor of discrimination when accompanied by manual response to tone, which operates in lengthening reaction time, also operates to alter the brain patterning more frequently than muscular response without discrimination?

Pursuing the analysis of the data on 'effectiveness' still further, we find a rather clear cut relationship between the complexity of the reactive requirements of the organism and the effectiveness of the tone in desynchronizing the cortical response. This correlation can be represented in two parallel series somewhat as follows:

Situation—	No Response (2 tones)	Simple Muscular Response *or* Discrimination without Response	Discrimination *and* Response
Effectiveness—	27%	40%	62%

Postulating that certain cortical changes which occur in response to two tones are less operative in response to one tone, one can add another segment to the series at the left end, namely, No Response (1 tone) 11 percent effective (7).

Another possible factor operating to reduce the effectiveness of tone in disturbing the Berger rhythm is adaptation. As stated in the results, "the effectiveness under the second experimental conditions was lower than it was in the discriminatory response situation." Adaptation may have operated here because two previous series of tones had been presented, and also because the conditions involved are somewhat similar to those in the two control series, namely, S is not required to make a discriminatory reaction and can therefore assume a relatively indifferent attitude toward the stimulus. The reduction in effectiveness of tone to its lowest point, in the second control situation, may also be due to adaptation.

It is apparent from the results on effectiveness, first, that even when S is most neutral to the stimuli, the effectiveness for a two-tone series such as we used is greater than is usually found for a one-tone series (7). Undoubtedly the presentation of two tones of different frequency introduces an 'attention' factor which is responsible for the high percentage of effectiveness reported. Secondly, the effectiveness of tone in depressing the cortical rhythm can be increased by altering the 'mental set' of the subject, by both discrimination and response.

Relating the complexity of the reaction organization to latent time of blocking of the Berger rhythm, we find that the correlation observed with effectiveness does not hold. The latencies are shortest under simple muscular response conditions, slightly longer during discriminatory response and longest in the control situations. Considering only the response segments for the moment, it appears that the determinants of latent time of blocking of the cortical rhythm may be common to the reaction time mechanism, since reaction time and latent time both tend to change in the same direction. But the two reactions do not very in proportion, from one situation to another. Our data show that although both 'times' are reduced in the speed response situation as compared with the discriminatory response situation, the magnitude of the reduction for reaction time is 35 percent, while for latent time it is only 8 percent. However, considering the absolute values of the latent and reaction times, they tend to become equal under speed response conditions. A tabulation of the data for all subjects shows that in 74 percent of the discriminatory response records the latent time of blocking was shorter than the manual reaction time, whereas in only 47 percent of the speed response records was this true. It may be that the reaction times become shorter than the latencies only by virtue of the fact that the former can be reduced so materially by changing the response situation to a simple one. One might well ask how reaction time, which involves receptor, adjustor and effector, can possibly be shorter than latent time, which presumably requires only receptor and the central mechanism in the response of which

it is a measure. The explanation appears to be one of different neural levels of action. The simple speed response soon becomes automatic and does not require central direction once the set has become fixed.

Viewing these relationships from another standpoint, the longest mean latent time for blocking out the cortical rhythm by tonal stimulation was .44 sec., and this time is obtained under passive, non-response conditions. The longest mean reaction time reported in this experiment was .45 sec., observed under discriminatory response conditions. Furthermore, the reaction time could be lengthened considerably by further complication of the discriminatory situation. The cortical response, on the other hand, is not subject to such a wide variability.

Considering only the data on latencies, it should be noted that whatever the nature of the discriminatory reaction, the latent time of blocking was reduced, not only for the tone eliciting the response (high) but also for the tone for which the subject was instructed not to respond (low). However, this mechanism apparently did not operate to increase effectiveness for the low tone.

Summary and Conclusions

It was the purpose of this study to determine the changes which occur in the Berger rhythm in response to auditory stimulation under certain conditions of 'mental set,' with particular reference to latent time of blocking and effectiveness of the stimulus. The subject was presented a random series of high and low tones (250 and 120 d.v., respectively, and equated for loudness), under the following experimental conditions: (1) control (non-response), (2) discriminatory response to high tone only, (3) speed response to both tones, (4) second control (non-response). Two thousand nine hundred and fourteen records from eight subjects were read.

The following results were obtained:

1. The mean latent times for the high and low tonal stimulations were approximately the same in any given situation.

2. The latencies were reduced by 16 percent when the subject was required to make a manual discriminatory response to the tones.

3. They were reduced by an additional 7 percent when the subject made a manual speed response to both tones.

4. The variability of these measures was significantly less under both response conditions than in either control situation.

5. The effectiveness of tone in depressing the Berger rhythm when the subject made a discriminatory response was approximately twice that obtained under control (non-response) conditions.

6. The reaction time was significantly less when the subject made a speed response to both high and low tones than when he made a discriminatory response to the high tone alone, the magnitude of the difference being 35 percent.

7. In 74 percent of the discriminatory response records the latent time of blocking was shorter than the manual reaction time, whereas in only 47 percent of the speed response records did this relationship obtain.

8. Qualitative evaluation of the brain wave records revealed altered patterns and shifting characteristics of the wave form under the various experimental conditions.

9. The cortical patterning correlated with "mental set" to make discriminatory and speed responses operated to reduce the blocking time to tone and to increase the effectiveness of tone in altering the brain potential rhythm.

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THE EFFECT OF FREQUENCY OF REINFORCEMENT UPON THE LEVEL OF CONDITIONING

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Psychology has accepted the following two laws of conditioning proposed by Pavlov (9): (1) paired stimulation of a neutral stimulus with an original or US,[1] under certain conditions of time and intensity, leads to the development of a CR to the neutral stimulus; (2) repeated presentation of the CS without the US leads to the weakening and gradual disappearance of the CR (experimental extinction). Upon the basis of these laws it has been assumed that once a CR be established, for it to be maintained, the CS must always be followed by the US; furthermore, if the US fails to follow the CS even occasionally, the CR will be weakened. This assumption is open to question, for in the familiar situation where dogs are conditioned to forelimb flexion, conditioned flexion develops and is maintained at a high response-level, when the US (shock) follows the CS only upon response-failure (4). It is important, therefore, to find how the frequency of CR varies with the frequency of US application, once conditioning be set up in accordance with Pavlov's first law.

Experimental Procedure

In order to investigate the problem more thoroughly, three groups of four dogs, each with a different type of CR, were tested. Each type of response was conditioned to bell, the animals being placed in a light-shielded, sound-proofed test-chamber with the experimenter observing through a one-way glass screen. The stimuli were electrically controlled with a telechron motor making each stimulus-sequence identical.

[1] Abbreviations: US = Unconditioned (original) Stimulus; UR = Unconditioned (original) Response to US; CS = Conditioned (substitute) Stimulus; and CR = Conditioned Response.

Twenty trials per day were given as the test-unit. The four animals in group A were placed in a stock where the strap of a lever attached to the wrist of the left forelimb permitted flexion of that member. This movement, evoked by shock to the wrist of the paw, was conditioned, shock being administered consistently whether the animals responded or not. The bell was 2 seconds in duration and was followed immediately by the shock which lasted for 1/10 of a second. Once 100 percent flexion to bell was reached, four additional test-periods were given. The mean of these twenty scores (five from each animal) gives the norm of group A for consistent shock reinforcement. Group B received similar treatment to group A except that conditioned flexion to bell was not followed by shock. Once 100 percent shock-avoidance was obtained, after each flexion, a biscuit of food was automatically dropped in the food-box to the right of the animal at the end of the stimulus (1). If conditioned flexion to bell failed, there was no food.[2] When a series of 100 percent conditioned flexion to bell reinforced by food was reached, four additional test-periods were given to establish a norm in the same manner as with group A. A fistula was made of the duct of the left parotid salivary gland of the animals in group C. By sealing a disk attached to a suitable hydraulic system over the fistula with wax, salivary secretion could be measured in a glass capillary tube on a millimeter scale above the observer's screen of the experimental chamber. Successive combinations of bell-food were given at twenty trials per day until five consecutive periods of 100 percent consistent conditioned salivation was obtained. The bell was 10 seconds in duration and food was delivered in the food-box to the right of the animal immediately afterwards.

Each group was then appropriately reinforced eighty, sixty, forty, and twenty percent of the time. Each frequency of reinforcement was maintained for five test-periods and occurred first, second, third, and fourth in one animal of each group. The following schema of order of reinforcement-frequency is characteristic of each group:

	Order of Frequency of Reinforcement			
Animal No. 1	80%	60%	40%	20%
Animal No. 2	60%	40%	20%	80%
Animal No. 3	40%	20%	80%	60%
Animal No. 4	20%	80%	60%	40%

Two random orders of reinforcement were set up for each reinforcement-frequency and given in an ABBAA sequence. By this procedure, means computed for each of the four different frequencies of reinforcement for each group are made available for comparison with the mean-response under consistent reinforcement.

Experimental Results

The animals of group A, where conditioned flexion was reinforced with shock, gave very consistent results. The daily and mean scores for each animal under all frequencies of reinforcement tested are given in table I. The mean group response at 100% reinforcement was 94.75% (s.e. = 2.00%),

[2] This type of response differs from the usual Pavlovian CR, and is similar to the type R CR reported by Skinner (10) and by Konorski and Miller (7, 8). It is a truly 'conditioned response,' for flexion is elicited by bell, once a neutral stimulus, and reinforced by food, a stimulus at no time capable of evoking flexion (1).

TABLE I

FREQUENCY OF CONDITIONED FLEXION REINFORCED WITH SHOCK

The response-levels of each animal are given in the columns in percent under each frequency. The mean for each animal at any reinforcement-frequency is given to the right of the main column and the standard error of the mean response in the next column to the right. The mean group response is given at the foot of each column and the figure in parenthesis is its standard error.

Animal	100%	Mean	s.e.	80%	Mean	s.e.	60%	Mean	s.e.	40%	Mean	s.e.	20%	Mean	s.e.
No. 1	100			100			100			100			100		
	90			100			95			100			100		
	95			100			100			100			100		
	70			100			100			100			100		
	100	91	5.57	100	100	0.00	100	99	1.00	95	99	1.00	100	100	0.00
No. 2	100			100			100			100			90		
	95			85			100			100			100		
	100			95			100			90			100		
	100			90			100			90			85		
	80	95	3.59	95	93	2.25	100	100	0.00	100	96	2.45	100	95	3.16
No. 3	100			100			100			100			100		
	100			100			100			100			100		
	100			100			100			100			100		
	100			100			100			100			100		
	100	100	0.00	100	100	0.00	100	100	0.00	100	100	0.00	100	100	0.00
No. 4	100			100			80			90			80		
	100			85			85			100			75		
	100			95			90			95			65		
	85			85			100			95			75		
	80	93	4.36	75	88	4.36	95	90	3.54	95	95	1.58	80	75	2.50
	94.75 (2.00)			95.25 (1.66)			97.25 (1.28)			97.50 (0.85)			92.50 (2.46)		

at 80% reinforcement 95.25% (s.e. = 1.66%), at 60% reinforcement 97.25% (s.e. = 1.28%), at 40% reinforcement 97.50% (s.e. = 0.85%), and at 20% reinforcement 92.50% (s.e. = 2.46%). There is a definite increase in response-level as the frequency of reinforcement decreases down to 40%, with a decrease in response-level at 20% reinforcement below that at all other reinforcement-frequencies. This trend can easily be seen in Fig. 1. The difference in mean response between 100% and the other frequencies of reinforcement is + 0.50% (s.e. = 2.60%) at 80% reinforcement, + 2.50% (s.e. = 2.37%) at 60% reinforcement, + 2.75% (s.e. = 2.17%) at 40% reinforcement, and − 2.25% (s.e. = 3.17%) at 20% reinforcement (Fig. 1). The technique devised by Fisher (6) was used to test the significance of these differences. The ratio of any difference to its own standard error is here

called *t*. With the *t* value, one can enter 'Student's Tables' and find the *p* value. When *p* is less than .02 (which signifies that the difference in question might be expected twice in 100 samples drawn at random from a homogeneous population), the difference is regarded as significant. The *p* values for the differences above are 0.42, 0.16, 0.10, and 0.15 respectively. Since all of these differences would be expected to occur by chance more than once in 100 times, they are hence not signifi-

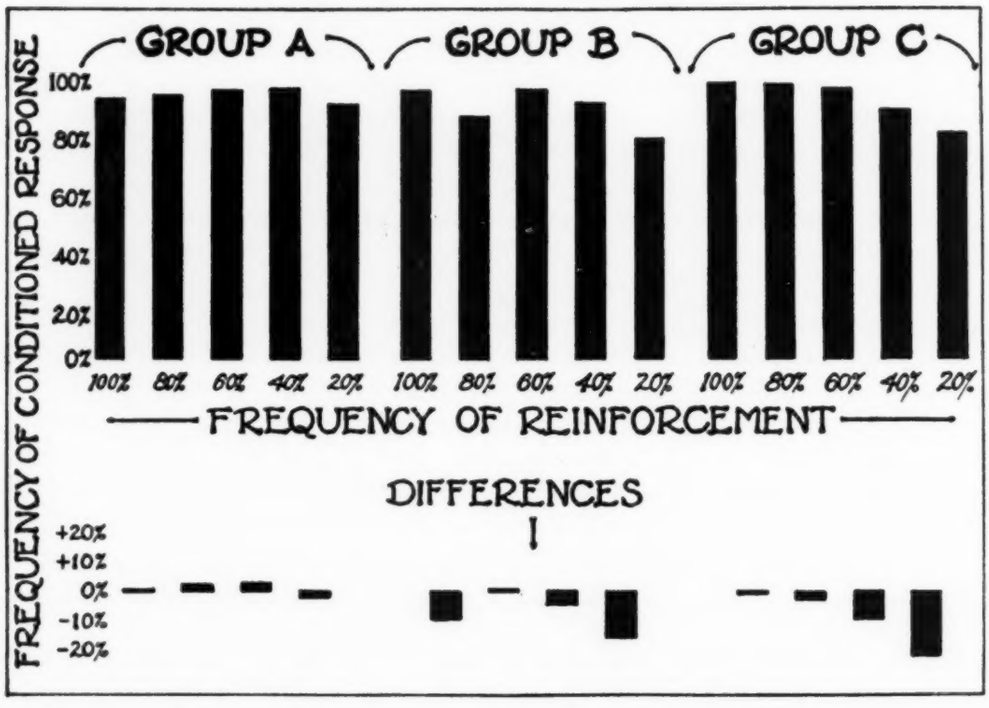

FIG. 1. The small histograms represent the mean difference in frequency of response between the level at 100% reinforcement and that at 80% reinforcement, between 100% and 60%, between 100% and 40%, and between 100% and 20% reinforcements. For each group, the difference at the left is that between 100% and 80% reinforcements, going in order to the right where the extreme is the difference between reinforcement at 100% and at 20%.

cant. Therefore, within the scope of this experiment, frequency of shock reinforcement of the conditioned flexion response does not affect the frequency of its appearance. The small standard error of the mean response-frequency at any frequency of reinforcement shows the stability of each response-level under each condition of reinforcement. On the other hand as the frequency of reinforcement decreased, there was a progressive decrease in vocal response, diffuse

behavior, and general restlessness. With constant reinforcement, flexion responses of the right forelimb were frequent, occurring sometimes alone and sometimes in alternation during the stimulus period with left forelimb flexion. The frequency of right forelimb flexion (shock was never applied to the wrist of the right limb) decreased as the frequency of shock reinforcement decreased. On the whole, the response-pattern became more unitary and operated with less complication from postural change and general bodily response when shock reinforcement was infrequent. In view of the biological significance of shock, this change in quality of the response-pattern is not surprising.

With group B, where left forelimb-withdrawal was reinforced by food, the flexion response-level at 100% reinforcement was 97.25% (s.e. = 0.92%), 88.25% (s.e. = 4.01%) at 80% reinforcement, 97.75% (s.e. = 0.92%) at 60% reinforcement, 93.25% (s.e. = 1.79%) at 40% reinforcement, and 81.25% (s.e. = 4.70%) at 20% reinforcement (table II and fig. 1). The difference in mean response at 100% reinforcement and 80% reinforcement is − 9.00% (s.e. = 4.12%). The response-level at 60% reinforcement is 0.50% (s.e. = 0.92%) greater, at 40% is 4.00% (s.e. = 1.94%) less, and at 20% is 16.00% (s.e. = 4.79%) less than at 100% reinforcement. There is an apparent, but not regular, decrease in response-level as the frequency of reinforcement decreases. The irregularity in response at the different reinforcement-frequencies, the relatively low response-level at 80% reinforcement as compared with the response-levels at 100% and 60% reinforcements, is readily explained by examination of animal No. 2. This animal, with the reinforcement order 60%, 40%, 20%, 80%, gave at 80% reinforcement only 70% response, not recovering from the 65% response-level at 20% reinforcement. It was almost impossible to maintain the experimental conditions for this animal, since flexion had to occur to bell before it could be reinforced with food. Therefore, animal No. 2 was not reinforced 80% of the time, but was given the opportunity of reinforcement 80% of the time. As the response-level had dropped so low under conditions

of 20% reinforcement, it took three days under opportunity of 80% reinforcement for the response-level to rise (table II). Once recovery of the response had taken place, this animal maintained a high level at 60% and 40% reinforcements (100% and 96% respectively). The other animals did not drop so low in response at 20% reinforcement and hence recovered more rapidly at 80% reinforcement. One might

TABLE II

FREQUENCY OF CONDITIONED FLEXION REINFORCED WITH FOOD

The response-levels of each animal in group B are given in the columns in percent under the frequency of reinforcement. The mean of each animal at any reinforcement frequency is given to the right of the main column and the standard error of the mean response in the next column to the right. The mean group response is given at the foot of each column and the figure in parenthesis is its standard error.

Animal	100%	Mean	s.e.	80%	Mean	s.e.	60%	Mean	s.e.	40%	Mean	s.e.	20%	Mean	s.e.
No. 1	100			100			90			95			75		
	85			100			100			95			85		
	100			95			95			100			80		
	95			100			100			90			80		
	100	96	3.67	90	97	2.00	95	96	1.87	85	93	2.55	80	80	1.58
No. 2	100			25			100			100			95		
	95			65			100			100			100		
	95			100			100			100			50		
	100			70			100			90			40		
	95	97	1.22	90	70	12.95	100	100	0.00	90	96	2.45	40	65	13.42
No. 3	100			95			100			100			100		
	100			100			100			100			100		
	90			100			100			100			100		
	100			100			100			100			100		
	100	98	2.00	95	98	1.22	100	100	0.00	100	100	0.00	100	100	0.00
No. 4	100			80			95			90			100		
	100			80			90			90			100		
	95			95			100			75			80		
	100			90			95			85			55		
	95	98	1.22	95	88	3.39	95	95	1.58	80	84	2.96	65	80	9.08
	97.25 (0.92)			88.25 (4.01)			97.75 (0.92)			93.25 (1.79)			81.25 (4.70)		

then expect a relatively stable response-level at the reinforcement-frequencies 100%, 80%, and 60% with a progressive decrease when reinforcement occurs 40% and 20% of the time. If Fisher's technique be applied to the differences, one finds that no difference is significant except that between frequency of response at 100% reinforcement and that at 20% reinforcement. Therefore, frequency of conditioned flexion

reinforced by food does not vary with frequency of reinforcement, except when the reinforcement occurs 20% of the time. As with group A, the internal consistency of response at any reinforcement-frequency is apparent by the small standard error of the mean group response, excepting of course the performance of animal No. 2 which has been discussed above. There was no marked behavior which could be interpreted as evidence that the animals were frustrated when food-reinforcement was decreased. Occasionally, the animals turned to the foodbox or flexed the left forelimb between presentations of the stimulus, but on the whole there was calm acceptance of the decrease in frequency of food-reinforcement.

Group C, conditioned to salivation with food the US, gave a mean response of 100% (s.e. = 0.00%) with 100% reinforcement, 99.50% (s.e. = 0.50%) at 80% reinforcement, 97.50% (s.e. = 2.50%) at 60% reinforcement, 91.00% (s.e. = 4.10%) at 40% reinforcement, and a mean response of 82.75% (s.e. = 4.76%) at 20% reinforcement (table III and fig. 1). The difference in mean response-frequency with 100% reinforcement is − 0.50% (s.e. = 0.50%) at 80% reinforcement, − 2.50% (s.e. = 2.50%) at 60% reinforcement, − 9.00% (s.e. = 4.10%) at 40% reinforcement, and − 17.25% (s.e. = 4.76%) at 20% reinforcement. The *p*. values of the differences are 0.17, 0.17, 0.01, and 0.00 respectively. The progressive decrease (easily seen in fig. 1) in frequency of response as the frequency of reinforcement decreases is therefore significant only when reinforcement is given 40% and 20% of the time. The intensity of the conditioned salivary response likewise decreases as the frequency of reinforcement is decreased. The mean intensity of response for the group was 46.20 mm (s.e. = 4.28 mm) at 100% reinforcement, 35.15 mm (s.e. = 4.40 mm) at 80% reinforcement, 36.32 mm (s.e. = 4.82 mm) at 60% reinforcement, 27.66 mm (s.e. = 4.98 mm) at 40% reinforcement, and 16.25 mm (s.e. = 2.61 mm) at 20% reinforcement. The differences, as with differences in frequency of response, are significant only at 40% and 20% reinforcements. The relative constancy in magnitude of the standard errors of both frequency

and intensity of response show the stability maintained under all frequencies of reinforcement, even when response differed significantly from that under consistent reinforcement. The daily scores of the animals likewise show this same characteristic (Tables III and IV). Latency of conditioned flexion is slightly less at 80% (3.02 sec., s.e. = 0.22 sec.) and 60% reinforcements (3.15 sec., s.e. = 0.24 sec.) than at 100%

TABLE III

FREQUENCY OF CONDITIONED SALIVATION

The response-levels of each animal in group C are given in the columns in percent under the frequency of reinforcement. The mean of each animal at any reinforcement frequency is given to the right of the main column and the standard error of the mean response in the next column to the right. The mean group response is given at the foot of each column and the figure in parenthesis is its standard error.

Animal	100%	Mean	s.e.	80%	Mean	s.e.	60%	Mean	s.e.	40%	Mean	s.e.	20%	Mean	s.e.
No. 1	100			100			100			90			100		
	100			100			100			100			100		
	100			100			100			55			80		
	100			100			100			40			65		
	100	100	0.00	100	100	0.00	100	100	0.00	100	77	12.40	90	87	6.60
No. 2	100			100			100			100			100		
	100			100			100			100			85		
	100			100			100			95			100		
	100			100			100			55			100		
	100	100	0.00	100	100	0.00	100	100	0.00	85	87	8.46	70	91	5.84
No. 3	100			100			100			100			75		
	100			100			100			100			40		
	100			100			100			100			40		
	100			90			100			100			65		
	100	100	0.00	100	98	2.00	50	90	10.00	100	100	0.00	50	54	6.97
No. 4	100			100			100			100			100		
	100			100			100			100			100		
	100			100			100			100			100		
	100			100			100			100			95		
	100	100	0.00	100	100	0.00	100	100	0.00	100	100	0.00	100	99	1.00
	100 (0.00)			99.50 (0.50)			97.50 (2.50)			91.00 (4.10)			82.75 (4.76)		

reinforcement (3.28 sec., s.e. = 0.31 sec.); slightly greater at 40% (4.25 sec., s.e. = 0.44 sec.) and significantly greater at 20% (4.34 sec., s.e. = 0.37 sec.) than at 100% reinforcement.

These animals, as a group, showed no consistent behavior which might be interpreted as frustration when the frequency of food reinforcement was decreased. One animal, No. 2,

given the reinforcement order 20%, 80%, 60%, 40% did on the second and third days of 20% reinforcement show evidence of frustration. When food consistently failed to appear after the CS, the animal whined and was restless. The restlessness increased until the animal tore off the salivary disk. However, at no other time did behavior of this kind appear in animal No. 2, nor at any time in the other animals.

TABLE IV

INTENSITY OF SALIVARY RESPONSE

The daily scores of magnitude of salivary response for each animal of group C are given in the columns in millimeters (1 mm. = 0.00167 c.c.) under each frequency of reinforcement. The mean of each animal at any reinforcement frequency is given to the right of the main column and the standard error of the mean in parenthesis just below the mean. The mean group response is given at the foot of the main columns and the figure in parenthesis just below the mean is its standard error.

Animal	100%	Mean	80%	Mean	60%	Mean	40%	Mean	20%	Mean
No. 1	19.75		25.50		31.50		12.00		11.75	
	18.00		19.00		18.25		27.00		16.00	
	21.75		14.75		21.75		5.00		5.50	
	21.75	20.50	13.50	19.85	22.00	20.35	4.25	12.20	6.00	9.30
	21.50	(0.74)	26.50	(2.68)	8.25	(3.74)	12.75	(4.90)	7.25	(3.93)
No. 2	47.25		40.75		57.75		80.25		37.75	
	52.75		49.00		74.25		82.00		14.75	
	63.75		50.50		47.75		12.25		33.50	
	38.75	54.35	88.25	59.80	81.50	60.50	6.75	38.30	39.00	26.20
	69.25	(5.52)	69.50	(8.63)	41.25	(7.65)	10.25	(17.50)	6.00	(6.53)
No. 3	51.00		18.00		15.25		34.75		7.75	
	62.50		24.75		20.50		28.75		3.25	
	79.00		29.75		17.50		31.35		4.00	
	56.50	62.00	20.75	22.75	27.50	21.25	17.00	26.32	6.50	6.20
	61.00	(4.48)	20.50	(2.06)	6.75	(3.62)	19.75	(3.42)	9.50	(1.14)
No. 4	63.75		17.50		48.75		47.50		27.50	
	37.75		50.75		57.50		20.25		30.50	
	62.50		34.75		27.50		30.00		20.00	
	49.25	47.90	44.00	38.40	33.00	46.95	48.00	33.85	21.25	23.50
	26.25	(7.09)	45.00	(2.72)	68.00	(7.52)	23.50	(5.97)	17.25	(2.09)
	46.20		35.15		36.32		27.66		16.25	
	(4.28)		(4.40)		(4.82)		(4.98)		(2.61)	

DISCUSSION

It is of interest to compare the results obtained with the animals of group A with the performance of two groups of guinea pigs reported by Brogden, Lipman, and Culler (2). The guinea pigs were conditioned to turn a rotating cage, with tone the CS and shock the US. One group of animals

was permitted to escape shock and rapidly reached a perfect score in conditioned cage-turning. The other group of animals received shock no matter whether they responded or not. These guinea pigs, after starting out as do pigs that are permitted to escape shock, began to drop off in frequency of conditioned cage-turning. They became erratic, rising and falling in random fashion from day to day; by the end of 500 trials the picture remained the same. Nothing was to be gained by turning the cage since the shock came anyway; so when the tone began, they literally 'sat tight,' held the breath, and sat tensely awaiting the shock. This is perfectly in keeping with the preparatory function of the CR (3). The guinea pigs made the best adaptation that could be made under the circumstances. The dogs of group A became conditioned as rapidly as do dogs that are permitted to escape shock by flexion. This is, however, the only point of similarity between two such groups of dogs. The animals of group A, unable to escape shock by flexion, yelped, were restless, assumed awkward postures, flexed the right forelimb alternately with the left, and were the very picture of distress when the bell sounded. Dogs that are permitted to escape shock give a stable, assured flexion to the CS. There is no restlessness, no yelping, nor evidence of distress. Why then do dogs flex the forelimb consistently when shock comes anyway? The patient in a dentist's chair grips the arms and sits tensely awaiting the time when the drill will produce pain. The absent-minded pedestrian who suddenly looks up to find an automobile on top of him, 'freezes'; his skeletal musculature tenses in anticipation of the collision. Such tension seems to be characteristic of mammals in the face of application of an unavoidable nocuous stimulus. It so happens that 'sitting tight' is the preparation the guinea pig makes for shock which it cannot avoid. On the other hand, flexion of the forelimb is the response the dog makes in preparation for an unavoidable shock to that member. Thus, in the case of the guinea pigs, the response did not coincide with the interest and aim of the experimenter; with the dogs, it did.

The most significant result of this study is the high level of response no matter what the frequency of reinforcement for any of the three conditioned responses. Conditioned flexion reinforced by shock did not drop below 92.50%; conditioned flexion reinforced by food did not drop below 81.25%; and conditioned salivation did not drop below 82.75%. Each of these scores was obtained under reinforcement 20% of the time. Certainly the assumption from Pavlov's laws (that the CS must always be followed by the US) does not hold. The significant analysis which Finch and Culler (**5**) have made of the role of the US in the conditioning process will tell us why. The unconditioned stimulus performs a dual role: (1) it determines the character of the response-pattern (shock applied to forepaw produces flexion and food taken by mouth evokes salivation); (2) it provides the incentive or drive needed to actuate the response. The CS takes over the first of these functions. But the US must be retained in its second function or else the CR will be extinguished. As long as the US is present some of the time functioning as an incentive, the CS will continue to elicit a response. An organism in which a CR has been established has learned something. It can respond appropriately to a signal in anticipation of the appearance of the US. An organism in which a given CR has been extinguished has not forgotten the CR. With the absence of the US there is no incentive for response. If after experimental extinction, the US be relinked with the CS in the usual experimental setting, the CR will appear within a few trials as it was before extinction. Therefore, once a CR be established, its maintainance is a function of motivation. From the experimental results obtained on three different conditioned responses it is evident that a relatively low frequency of reinforcement is capable of maintaining a CR at a high response-level.

Summary of Conclusions

The frequency of conditioned flexion reinforced by shock does not vary with the frequency of reinforcement. On the

other hand, there was a progressive decrease in vocal response, diffuse behavior, complication from postural position, flexion of the *right* forelimb, and general restlessness as the frequency of shock-reinforcement was decreased. The frequency of conditioned flexion reinforced with food is the same when reinforcement occurs 100%, 80%, 60%, and 40% of the time, but is significantly less at 20% reinforcement than at 100% reinforcement. There was no behavior on the part of the animals which could be interpreted as frustration when reinforcement was decreased. The frequency and intensity of conditioned salivation reinforced by food do not vary with reinforcement 100%, 80%, and 60% of the time, but are significantly less than that at 100% reinforcement, when reinforcement is maintained at 40% and 20%. The latency of conditioned salivation is the same for all conditions of reinforcement except at 20%, where it increases significantly. One animal showed evidence of frustration when reinforcement occurred 20% of the time.

In no case did the frequency of any of the three types of conditioned response drop below 80%. Once conditioning be established, maintainance of response-level depends upon the application of the US as an incentive. A relatively low frequency of reinforcement will maintain the CR at a high response-level. That frequency of CR is a function of incentive application is clearly shown by the performance of group B, where flexion was reinforced by food, a stimulus which was at no time capable of evoking flexion, and therefore functioned only as an incentive.

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STUDIES IN CONFIGURAL CONDITIONING

VI. Comparative Extinction and Forgetting of Pattern and of Single-stimulus Conditioning

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The Problem

In five preceding articles (**3**–**7**) the writer presented a series of results on salivary pattern conditioning—conditioning of salivation in adult human subjects to patterns rather than to single stimuli. The results indicated that pattern conditioning possesses a considerable number of characteristics that could by no means be predicted from the known facts of simple conditioning, and that these characteristics seem to be in some, if not very definite, way related to the properties and the arrangements of the stimuli in the patterns. Specifically, the most significant indications were: (1) Conditioning to a pattern of stimuli may be much greater than to the sum of the component stimuli of the pattern, or, even, the conditioning may be evoked only by the pattern while the components are totally ineffective (supra-summation). (2) The course of transfer or generalization of pattern conditioning differs radically from that of single stimulus conditioning (transposition *vs.* generalization). (3) The conditioning efficacy of various parts of patterns varies, and in the course of training to the total pattern this efficacy constantly shifts from the simpler to the more complex parts of the patterns (simple–complex tendency of patternization). (4) The Gestalt principles of patternization—similarity, proximity, continuity, closure, symmetry, and the like—do not hold for pattern conditioning or hold in a very limited fashion (no final static principles of CR patternization). (5) Attitudes and interest-differentials are very potent factors in pattern conditioning, determining whether the conditioning should be

to a part or to a pattern, or to what kind of part or pattern (attitudes as determinants of kind and degree of CR patternization).

In the present study the topic of investigation was extinction [1]—decrease or disappearance of CR upon non-reinforcement—and forgetting—decrease or disappearance of CR after a lapse of time. The questions in mind were: First, are there any significant differences between extinction and forgetting of pattern and of single stimulus conditioning? Second, if there are such differences, how are they related to the types of patterns of stimuli conditioned? No new conditioning experiments were made for this study; the old CRs of the 32 subjects to 26 types of stimuli patterns of the previous studies were utilized for the tests of extinction and forgetting.

Procedure

The writer's general salivary CR technique with adult human subjects has been described before (2), and will not be further detailed. It consists, first, of measuring salivation by increments in weights of dental cotton rolls (Johnson and Johnson, No. 3, 0.5 × 1.5 in.) inserted under the subjects' tongues for a short period of time, usually one minute. To prevent evaporation, scale-corrosion and absorption, the rolls are weighed in small envelopes and reweighed in the envelopes immediately after the removal of the cotton from the subjects' mouths. Since the cotton-in-the-mouth is by no means a totally inactive stimulus, periods of control salivation must always be rotated with experimental periods, but the weighing itself need not be more accurate than to one centigram, milligram accuracies being a superfluous refinement. Secondly, the technique involves presenting a *series* of stimuli during eating periods of 2–4 minutes and misinforming the subjects about the purpose of the experiment so as to forestall disturbing subjective attitudes and association-sets. Series of stimuli and comparatively long eating periods are used, as misinforming is unsuccessful and association-sets can hardly be averted with the traditional single-conditioned-stimuli-plus-brief-reinforcements procedure. Telling the subjects that the purpose of the experiment is to study 'the effect of eye-fatigue upon digestion' with visual conditioned stimuli, 'the influence of music upon salivation' with to-be-conditioned musical stimuli, and diverse imaginary 'learning and memory problems' with verbal stimuli, are serviceable 'misinforming' techniques.

The tests for both extinction and forgetting were begun one week after the end of the main conditioning experiments, 16 subjects being used for one set of tests and

[1] With the writer's new technique (see *Procedure*) of forestalling subjective attitudes by presenting series of stimuli during comparatively long eating periods and misrepresenting the true purpose of the experiment, extinction of salivary CRs in adult human subjects has been regularly observed. No such extinction was found, when attitudes were not ruled out, with the traditional single-stimuli-plus-brief-reinforcements method (2).

the remaining 16 for the other. The magnitudes of the CRs ranged at this time from 9 to 21 centigrams of net conditioned salivation (minus control salivation) per one-minute periods. The stimuli patterns were: (1) Alternate single flashes of small colored lights (2.5 volts, 3/8 in diam.) of the same or of different colors following each other at constant or at variable intervals. (2) Simultaneous flashings of two small lights of the same or of different colors at distances of 0.5, 1, 2, and 4 inches. (3) Simultaneous flashes of two lights of different color, size, and intensity at distances of 2 inches. (4) Simultaneous flashes of two large colored lights (36 c.p.) of different colors with one or two small white lights between. (5) Simultaneous flashings of 4 small green lights forming a horizontal line, an oblique line, a triangle, or a quadrilateral; of 10 green lights forming a horizontal line, a right angle, two adjacent right angles, 9 in a horizontal line and one light above; of 8 green lights forming a closed square, an open square, two adjacent open rectangles, a hooked square.[2] (6) Flashing a small green light and sounding a bell, flashing simultaneously a green light and a nonsense syllable. The single stimuli were of course any of the stimuli that composed the respective patterns. Both single stimuli and patterns were tested for conditioned salivation in one-minute periods during which 12–30 intermittent applications of the single stimuli or of the patterns were made. The extinction trials were given on two successive days: 10 trials each day, 5 one-minute tests of different conditioned stimuli in each trial, and 3-minute rest periods between trials. In testing for forgetting or retention only two trials were made each day: 1 week, 2 weeks, 4 weeks, 8 weeks, and 16 weeks after the end of the training periods. In no case was any reinforcement ever applied during the extinction or the forgetting trials. As in the original training experiment, the subjects were paid 50 cents an hour by NYA, and the experiment was conducted in a dimly lighted, fairly sound-proof room, between 3 and 5 o'clock in the afternoon. The 'given' purpose of the experiment was 'to study the effect of eye-fatigue upon digestion.'

Results

The results are presented in Tables 1–2. Each entry in these tables represents centigrams of net conditioned salivation (minus control salivation) in one-minute periods. Extinction is given as means of successive groups of 4 non-reinforced trials (the third mean is a result of the last two trials of the first day and the first two trials of the second day [3]); the entries for retention are means of two trials. The 'number of subjects' in each row of Table 1 is the combined number of subjects tested for extinction and for retention with the particular pattern and single stimulus described in the row. No subject was used for both tests—extinction and retention—but a considerable number of subjects were tested for more than one conditioned stimulus pattern, and in each

[2] These lights were in turn parts of larger patterns; see (6) for details.

[3] There was very little spontaneous recovery on the second day, perhaps because the extinction itself had not progressed very far the first day.

TABLE 1

EXTINCTION AND RETENTION OF SALIVARY CRs TO PATTERNS OF STIMULI AND TO THE COMPONENT STIMULI OF THE PATTERNS IN 32 ADULT HUMAN SUBJECTS

Each entry represents centigrams of conditioned salivation per one-minute periods. Subjects tested for extinction were not tested for retention, and vice versa.

Description of Pattern	Pattern or Single Stimulus Tested	Subjects (No.)	Extinction: Means of Successive 4 Trials	Retention after 1, 2, 4, 8, and 16 Weeks
Red light following green light and vice versa	Pattern.....	8	17, 14, 15, 13, 11	16, 14, 10, 9, 8
	Single light.....		14, 10, 9, 7, 5	12, 8, 4, 3, 3
Lights of same color following each other	Pattern.....	8	10, 9, 8, 7, 4	11, 10, 8, 6, 3
	Single light.....		9, 7, 5, 4, 0	9, 7, 3, 2, −1
Red and green lights at distances of 2 inches	Pattern.....	8	18, 17, 16, 15, 8	17, 14, 10, 10, 6
	Single light.....		12, 10, 9, 4, 2	11, 10, 8, 5, 1
Lights of same color at same distance	Pattern.....	4	14, 12, 10, 9, 6	16, 11, 7, 3, 0
	Single.....		12, 10, 7, 3, 1	13, 10, 6, 2, 1
Red and green lights at distances of 4 inches	Pattern.....	2	11, 10, 8, 6, 2	11, 10, 9, 4, 1
	Single.....		10, 9, 8, 2, 0	12, 8, 4, 2, 0
Red and green lights at distances of one inch	Pattern.....	2	14, 13, 12, 10, 8	15, 14, 10, 9, 5
	Single light.....		9, 8, 10, 8, 4	10, 7, 3, 2, 1
Red and green lights at distances of 0.5 inch	Pattern.....	2	15, 10, 8, 4, 2	11, 13, 14, 7, 4
	Single light.....		10, 9, 7, 3, 1	12, 10, 9, 3, 0
Lights of same color at same distance	Pattern.....	2	13, 8, 5, 2, 0	11, 9, 5, 2, 1
	Single.....		10, 7, 6, 3, 0	9, 7, 3, 1, 2
Red and green lights unequal in size and intensity	Pattern.....	2	14, 13, 12, 11, 10	16, 14, 12, 8, 5
	Larger light....		12, 10, 10, 9, 6	12, 10, 9, 7, 0
Green light and sound of bell	Pattern.....	2	9, 7, 5, 3, 3	8, 6, 4, 2, 1
	Single		8, 6, 3, 0, 0	6, 5, 2, 0, 0
Green light and nonsense syllable	Pattern.....	2	19, 17, 16, 11, 10	20, 18, 14, 13, 12
	Single.....		15, 12, 10, 8, 3	14, 11, 10, 2, 1
Means	Pattern.....		15, 13, 12, 10, 7	14, 12, 10, 8, 4
	Single stimulus.		11, 9, 8, 4, 2	11, 9, 5, 3, 1

case of testing both pattern and single stimuli CRs were of course determined. In the tables are also presented the mean magnitudes of the CRs, at each extinction and retention stage, of all the pattern and single stimuli trials, while in Table 2 are also given the results with equated means of these test conditions. These equated means were computed from only 'matched' trials, trials in which the initial magnitudes

TABLE 2

EXTINCTION AND RETENTION OF SALIVARY CRs TO PATTERNS OF STIMULI AND TO THE COMPONENTS OF THE PATTERNS IN ADULT HUMAN SUBJECTS

Each entry represents centigrams of conditioned salivation in one-minute periods. A different subject was used for each extinction and each retention experiment.

Description of Pattern	Pattern or Single Stimulus Tested	Extinction: Means of Successive 4 Trials	Retention after 1, 2, 4, 8, and 16 Weeks
Large red and green lights at distances of 3 in. from each other	Pattern.....	17, 15, 16, 13, 11	18, 13, 9, 7, 2
	Single stimulus.	14, 10, 9, 7, 4	13, 11, 4, 2, 0
Same lights with small white light between	Pattern.....	19, 16, 12, 9, 7	20, 14, 12, 5, 4
	Single.....	12, 6, 3, 0, 0	13, 10, 8, 3, 0
Same lights with 2 small lights between	Pattern.....	16, 16, 15, 13, 11	21, 16, 7, 2, 1
	Single.....	14, 8, 4, 2, 0	13, 11, 5, 2, 0
4 green lights in a horizontal line	Pattern.....	13, 11, 10, 12, 9	14, 10, 13, 5, 3
	Single.....	10, 9, 5, 2, 1	11, 12, 10, 0, 0
4 green lights in an oblique line	Pattern.....	15, 12, 10, 9, 7	14, 13, 3, 5, 1
	Single.....	13, 9, 4, 2, 0	14, 10, 6, 2, 1
4 lights forming a triangle	Pattern.....	21, 19, 17, 18, 11	20, 16, 14, 13, 11
	Single.....	13, 8, 3, 2, 0	14, 11, 7, 3, 1
4 lights forming a quadrilateral	Pattern.....	18, 17, 13, 11, 9	16, 11, 13, 14, 2
	Single.....	11, 10, 5, 3, −1	10, 8, 1, 2, 0
10 green lights in a horizontal line	Pattern.....	19, 17, 12, 10, 9	20, 15, 8, 4, 3
	Single.....	14, 10, 11, 6, −2	16, 11, 7, 3, 0
10 green lights forming a right angle	Pattern.....	21, 20, 22, 17, 13	22, 23, 18, 14, 10
	Single.....	14, 9, 4, 2, 0	14, 10, 4, 2, 1
10 green lights as 2 adjacent right angles	Pattern.....	20, 17, 21, 16, 15	19, 16, 18, 15, 14
	Single.....	15, 14, 9, 3, 2	16, 11, 8, 9, 3
10 green lights, 9 in a line and one above	Pattern.....	18, 15, 17, 15, 15	17, 15, 14, 16, 11
	Single.....	14, 9, 5, 3, 1	16, 19, 14, 10, 8
8 green lights forming a closed square	Pattern.....	22, 20, 24, 20, 17	19, 16, 18, 13, 11
	Single.....	17, 11, 10, 7, 2	15, 17, 11, 4, 6
8 green lights forming an open square	Pattern.....	16, 13, 10, 11, 13	18, 19, 20, 11, 14
	Single.....	14, 8, 3, 2, 1	16, 9, 7, 3, 0
8 green lights as 2 adjacent open rectangles	Pattern.....	20, 18, 23, 16, 10	14, 11, 10, 13, 9
	Single.....	15, 14, 10, 6, 4	15, 8, 3, 0, −1
8 green lights as a hooked square	Pattern.....	16, 18, 19, 20, 21	17, 13, 10, 11, 8
	Single.....	14, 11, 10, 9, 6	17, 13, 11, 9, 4
Means	Pattern.....	18, 16, 16, 14, 12	18, 15, 14, 10, 7
	Single stimulus.	14, 10, 6, 3, 1	14, 12, 7, 4, 2
Combined Means (both Tables)	Pattern.....	17, 15, 14, 12, 10	16, 14, 13, 9, 6
	Single stimulus.	13, 10, 7, 3, 2	13, 10, 7, 3, 1
Equated Means	Pattern.....	13, 12, 10, 8, 6	15, 12, 10, 8, 3
	Single stimulus.	13, 10, 7, 4, 1	15, 12, 9, 5, 2

of the pattern and the single stimuli CRs were equal; with two exceptions, the matched trials were not of the same pattern.

As seen from the results, the differences between pattern and single stimulus extinction and forgetting are rather pronounced. The combined means of the magnitudes of the CRs in successive stages of extinction were: 17, 15, 14, 12, and 10 (centigrams of conditioned salivation in one-minute periods) for the patterns of stimuli and 13, 10, 7, 3, and 2 for the single stimuli tests. In retention, the combined successive means were respectively: 16, 14, 13, 9, 6 and 13, 10, 7, 3, and 1. Expressing extinction and forgetting as percents of losses from the initial magnitudes of the CRs, the figures would be: 12, 18, 30, 41 and 23, 46, 77, 85 for extinction, and 13, 19, 44, 63 and 13, 46, 77, 92 for forgetting. Thus, in the last 4 trials the extinction for the single stimuli CRs was more than twice that of the pattern stimuli CRs and, after a lapse of 16 weeks, the forgetting of the former was nearly 50% greater than of the former. Since the initial CRs of the patterns were in practically all cases higher than those of the single stimuli, the equated means are highly instructive. It may be noted, by inspecting these means, that even here when the initial magnitudes of the CRs were equal, the percents of successive extinction of the single stimuli were 23, 46, 69, and 92 and of the patterns 8, 23, 38, and 54, while the forgetting losses were respectively 20, 40, 67, 87 and 20, 34, 47, 80. Apparently, the greater stability and persistence of pattern conditioning are due not only to quantitative but also to qualitative factors. On the other hand, the relations between pattern properties and resistance to extinction and forgetting are by no means clear-cut, although, on the whole, there seems to be some indication that the more complex patterns suffered the lesser losses.

Summary

1. Extinction and forgetting of salivary CRs to 26 patterns of stimuli and to the component stimuli of the patterns were studied in 32 adult human subjects. Extinction consisted of

testing 20 non-reinforced trials on 2 successive days, forgetting —of testing after 1, 2, 4, 8, and 16 weeks. Subjective attitudes were in all cases ruled out.

2. Both extinction and forgetting were much slower when the conditioned stimuli were patterns of stimuli than when they were components of these patterns. The differences were pronounced even when the initial magnitudes of the CRs were equal in both cases.

3. A lapse of 16 weeks resulted in nearly complete disappearance of CRs to single stimuli and in their reduction by two-thirds to patterns of stimuli. 20 non-reinforced trials on 2 successive days abolished 85% of the CRs to single stimuli but decreased the pattern CRs by only 41%.

4. No definite relations between pattern properties and resistance to extinction and forgetting was established. There was, however, some slight evidence that the more complex patterns were the more resistant.

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STUDIES IN THERMAL SENSITIVITY: 10. THE RELIABILITY OF SERIATIM WARM-MAPPING WITH UNTRAINED SUBJECTS

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In the preceding article of this series,[1] evidence was presented concerning the reliability of seriatim cold-mapping with untrained subjects. On the basis of good reliability coefficients between succeeding periods, consistent relations between average and individual scores, and the orderly patterning of the maps derived from average scores, it was concluded that seriatim cold-mapping is a dependable research technique for quantitative investigation. The same question now needs to be considered in regard to seriatim warm-mapping.

In the Dallenbach study with trained observers,[2] the 'warm spots' were mapped with a 1 mm diam. stimulator at 44–46° C. once on each of four different days upon the same skin area. In Fig. 1 are shown the individual maps and also composite charts on which are indicated the number of times each mm square was reported as warm during the four trials. As in the case of cold, the outcome is ambiguous. There is no direct evidence of high reliability. However, if the concept of 'warm spots' as discrete entities is abandoned, the composite maps present pictures of orderly but non-uniform sensitivity. The need for the seriatim technique is indicated in order that reliability of mapping may be established independently.

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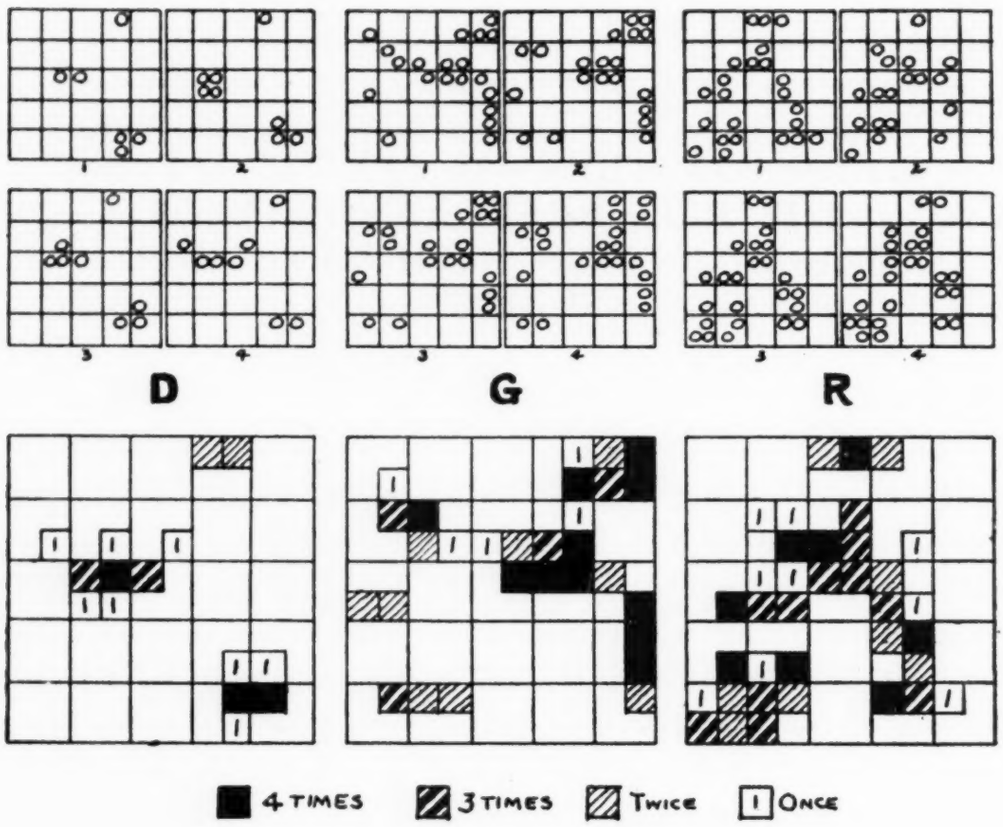

FIG. 1. Replotting of Dallenbach's warm-mapping.

PROCEDURE

Essentially the methods of this study were similar to those used with seriatim cold-mapping. A checkerboard pattern on the volar surface of the left forearm was stimulated in random order a number of times during each experimental period, giving scores which can be compared by the usual methods of correlation. In certain aspects, however, the procedure in warm-mapping differed from that used with cold:

1. *Individual and Group Experiments.*—The individual experiments were similar to those with cold. Two students alternated as subject and recorder for two consecutive periods of six stimulations each. In the group experiments, however, each group consisted of four students, acting in turn as experimenter, subject, recorder and 'thermostat,' the duty of the last-named being the maintenance of the stimulating temperature as close to 46° C. as possible. With this arrangement, only 5 stimulations could be made during a two-hour period, and no comparisons between consecutive periods of the same session were possible.

2. *Reports.*—For the individual experiments, only three categories were used: O, W and H (treated as 0, 1 and 2 in the computation of scores). In the group experiments, the categories were increased to four: 0, 1, 2 and 3. No assumption was made that 'hot' is qualitatively different from 'warm'; the range of experiences was treated as a continuum.

3. *Statistical Treatment.*—For the individual experiments, scores were computed simply by adding the numbers reported for the six stimulations. For the group experiments, scores developed in the same way were used in computing correlations

and in the table showing the distribution of scores (Tables 2 and 3). In making up the average score charts and maps (Figs. 2 and 3), these scores were reduced proportionately to a maximum of 12 (instead of 15) to make them more directly comparable with those obtained in the individual experiments and the earlier work on cold-mapping.

Variables and Artifacts

The obtained reliability coefficients are always resultants of a number of *variables* which seem to be inherent in the situation. These are: changes in the sensitivity of the area as a whole and of individual squares; the general ability of the subject to maintain standards of judgment, broad shifts of criteria levels and the improvement of discriminations with practice.

In addition, there may enter a multiplicity of *artifacts*, which it is desirable to control as far as possible. As in the case of cold, those artifacts which would tend to increase the size of the coefficients are probably of little moment. These have been given in detail in the preceding article,[3] and will not be repeated here. Among the artifacts tending to decrease the coefficients, mislocation of the squares in restamping, errors of the experimenter and errors of the recorder would probably enter to much the same extent as with cold. Special mention must be made, however, of four artifacts which appear to be of greater importance in warm-mapping:

1. *Adaptation.*—Loss of sensitivity during the latter part of the two-hour session in the individual experiments was frequently observed, although the interval between successive stimulations of the same square was approximately 10 minutes. In the group experiments, in which the spacing was 20 minutes and only 5 stimulations were made during the two-hour period, this was less evident.

2. *Vascular Effects.*—A leveling-off of the reports is likewise apparent in some of the individual experiments. This we may attribute provisionally to vasodilation, which would engender a diffuse warmth over the entire area. This also was much more apparent in the individual experiments.

3. *After-effects.*—Whereas after-images were occasionally noted with cold stimulation, subjects rarely found them confusing. With warm, however, these were often so strong and persistent as to constitute a severe annoyance, which certainly added nothing to the accuracy of judgment.

4. *Spread.*—Judgments of cold can be made so quickly that spread of the stimulus is at a minimum. In the case of warmth, the stimulation must be longer to permit the experience to reach its peak, and this may allow a greater spread to adjacent areas.

Note must also be made of the well-recognized subjective difference in the experiences of cold and warm. Cold typically 'snaps on' to its full intensity, and seems rather sharply delimited as to area. Warmth wells up slowly and seems much more diffuse; the peak of the experience is often difficult to determine.

Results

The reliability coefficients derived from the *individual* experiments are given in Table 1. A few subjects were able to achieve nearly as high values as the best obtained in the

[3] Op. cit.

TABLE 1

INDIVIDUAL EXPERIMENTS

3 mm diam. stimulator—46° C.

Subj. Init.	Correl. ×100	Distribution of Scores				
		0–1	2–3–4	5–6–7	8–9–10	11–12
TGW.....	89	5	17	12	7	8
		1	16	13	12	4
FFW.....	87	0	7	17	9	17
		0	5	15	14	16
EKG.....	82	0	2	30	10	8
		0	2	36	6	6
RST.....	73	0	7	33	7	3
		1	6	37	2	4
JAF.....	72	0	0	31	15	4
		0	7	37	3	3
LRW.....	71	1	13	25	8	3
		5	13	25	7	0
JCC.....	59	6	17	23	4	0
		31	17	2	0	0
JHW.....	58	1	8	29	10	2
		1	10	31	5	3
2 mm diam. stimulator—46° C.						
CRS.....	92	2	9	16	15	8
		2	10	13	11	14
SRS.....	87	12	16	8	3	11
		18	14	8	2	8
HBG.....	74	0	21	16	6	7
		2	15	22	4	7
WDS.....	65	0	1	25	18	6
		0	0	12	21	17
MLD.....	63	30	18	2	0	0
		43	5	2	0	0
DLD.....	59	0	1	14	25	10
		0	4	34	9	3
SBP.....	52	0	4	37	8	1
		0	0	42	8	0
RES.....	50	2	13	31	4	0
		0	6	42	2	0
CDB.....	46	2	5	13	17	13
		0	0	4	20	26
MRD.....	42	2	25	17	5	1
		11	32	7	0	0

cold-mapping, but the general level is distinctly below the cold figures, especially with the 2 mm stimulator. Distributions of scores show marked shifting between the first and second consecutive periods, sometimes negative and sometimes positive in direction.

The reliability coefficients derived from the *group* experiments are shown in Table 2, where all possible intercorrela-

TABLE 2

CORRELATIONS × 100—GROUP EXPERIMENTS

3 mm diam. stimulator—46° C.

Subj. Init.	Interval		
	One Day	Two Days	Three Days
WB.....	42	62	48
CD.....	76 50 68	56 52	51
AED.....	65 77 62 79*	54 62	
JED.....	75	77	74
MLF.....	71		
JH.....	77 91 75	75 77	71
ABH.....	72 83	66	76 90 74
KK.....	73 87 89	70 84	71
JRL.....	70 57*	60 51	73 67
TR.....	85 84 85	76 70	67
RW.....	66 67 64	62 62	49
WW.....	61 73		

* A.M. and P.M. same day.

tions are given. Again the values are definitely lower than those from the group experiments with cold. Even if we consider only the peak performance of each subject, the same inferiority exists. Only four of the subjects reached .85 or better and only three more .75 or better. On the other hand, it will be noted that the values rarely run below .60. The plotting of average against individual scores (Fig. 2) confirms this general characterization. Although there is definite grouping along the diagonal, the range of dispersion is wider and there are more 'wild shots' than occurred with cold.

Only in the maps derived from average scores (Fig. 3) do we find results which roughly equal those obtained with cold. These maps show the same general *orderliness* which was

TABLE 3

DISTRIBUTION OF SCORES—GROUP EXPERIMENTS

3 mm diam. stimulator—46° C.

Subj. Init.	Date (July)	0–1	2–3	4–5–6	7–8	9–10–11	12–13	14–15
WB.....	18	1	4	21	9	10	3	2
	20	2	9	27	9	2	0	1
	21	0	6	30	8	5	1	0
CD.....	19	0	0	4	9	26	10	1
	20	0	0	2	17	21	10	0
	21	0	0	6	16	19	3	6
	22	0	0	0	5	22	19	4
AED....	19	0	0	6	12	22	8	2
	20	0	0	6	14	19	10	1
	A.M. 21	0	0	8	9	20	8	5
	P.M. 21	0	0	2	9	19	17	3
JED.....	18	0	0	0	7	18	6	19
	19	0	0	4	10	13	10	13
	21	0	0	3	10	19	13	5
MLF....	21	3	5	10	3	20	4	5
	22	0	0	8	6	18	6	12
JH.....	18	1	0	18	9	14	3	5
	19	1	2	34	3	4	4	2
	20	1	1	37	2	7	2	0
	21	2	4	37	4	3	0	0
ABH....	18	0	0	9	10	11	7	13
	19	0	0	5	5	9	12	19
	21	0	0	10	10	13	9	8
	22	0	3	9	11	12	6	9
KK.....	18	0	0	6	14	15	7	8
	19	0	0	18	5	12	5	10
	20	0	0	25	7	2	4	12
	21	0	0	28	3	6	6	7
JRL.....	19	1	4	14	12	13	4	2
	20	1	0	17	8	19	2	3
	A.M. 22	0	0	15	16	14	4	1
	P.M. 22	0	0	3	14	21	10	2
TR.....	18	2	13	18	6	7	3	1
	19	15	10	21	3	1	0	0
	20	9	19	19	3	0	0	0
	21	21	9	18	2	0	0	0
RW.....	18	0	2	7	15	10	12	4
	19	0	0	9	14	17	6	4
	20	0	1	30	9	10	0	0
	21	0	0	30	19	1	0	0
WW(1)...	19	0	0	1	5	19	13	12
	20	0	0	0	13	23	11	3
WW(2)...	21	0	1	6	16	16	11	0
	22	0	0	14	12	18	6	0

noted with 17° C. stimulation. Although the total range of scores is narrower, there is a clear tendency for identical and nearly-identical numbers to be grouped in nearly every map.

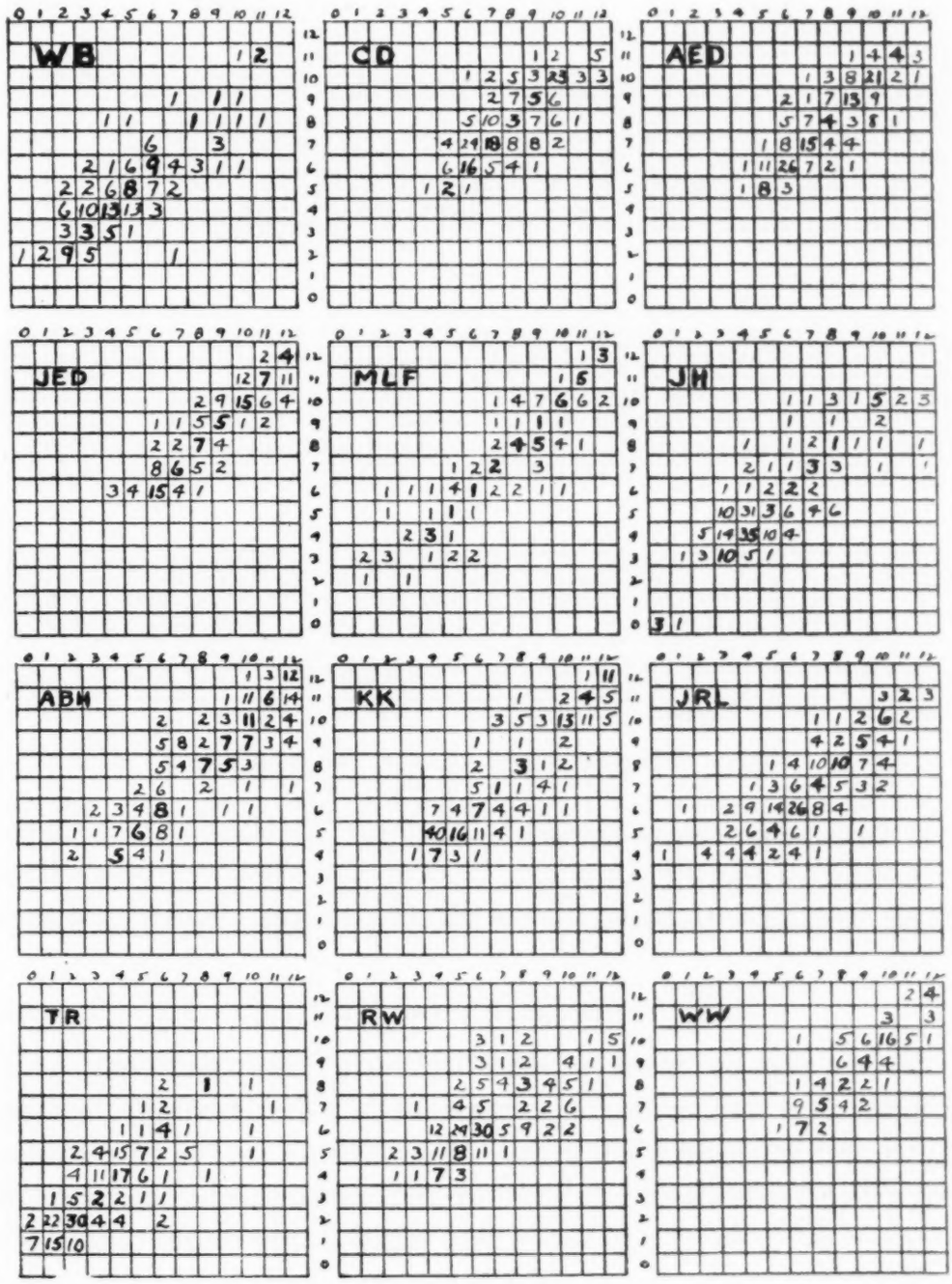

FIG. 2. Average against individual scores.

As a matter of interest, the maps developed from the individual experiments with a 2 mm stimulator (average of

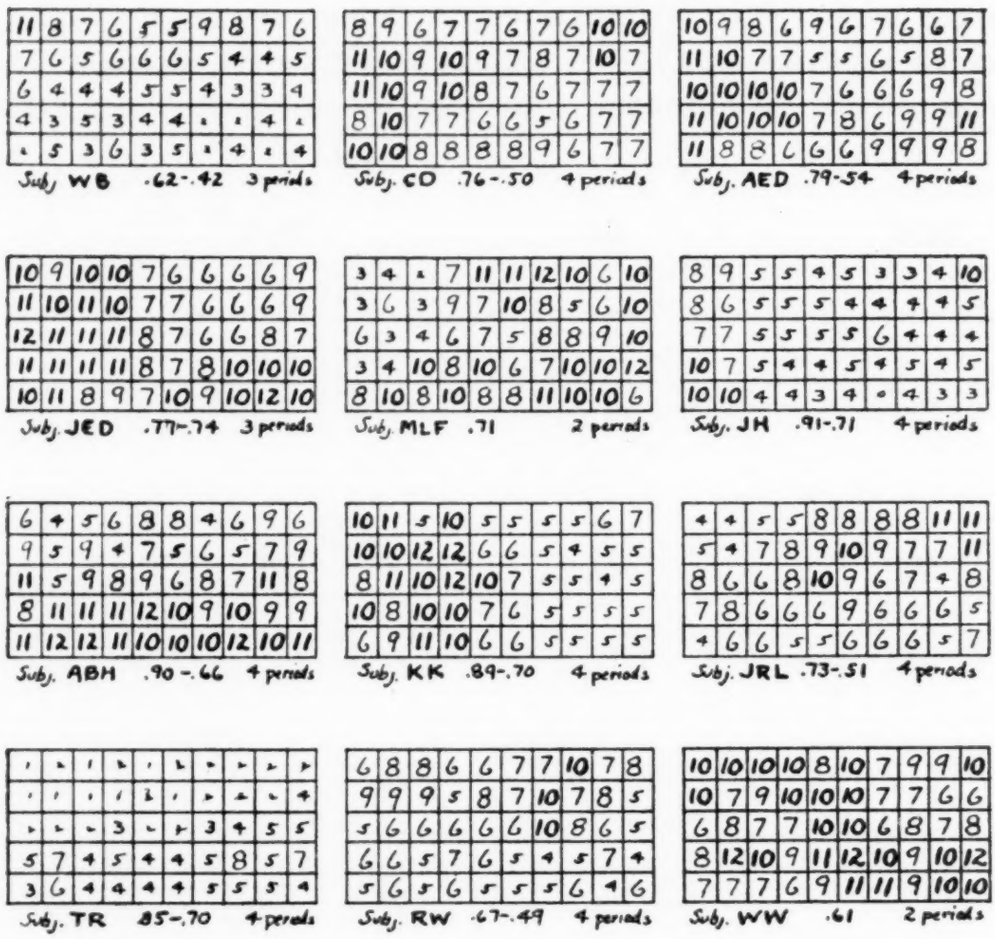
Subj. WB .62-.42 3 periods
Subj. CO .76-.50 4 periods
Subj. AED .79-.54 4 periods
Subj. JED .77-.74 3 periods
Subj. MLF .71 2 periods
Subj. JH .91-.71 4 periods
Subj. ABH .90-.66 4 periods
Subj. KK .89-.70 4 periods
Subj. JRL .73-.51 4 periods
Subj. TR .85-.70 4 periods
Subj. RW .67-.49 4 periods
Subj. WW .61 2 periods

FIG. 3. Maps of average scores—3 mm stimulator.

only two periods) are shown in Fig. 4. Although the orderliness is less apparent in these, this may be in part an artifact of the smaller number of cases used in computing the average scores.

INTERPRETATION OF RESULTS

From the outcome of the individual experiments, it is evident that the seriatim scheme used in cold-mapping is of questionable value for warm. With stimulations 10 minutes apart, the artifacts of adaptation and vascular changes appear to enter even in the cases where reasonably high reliability coefficients are obtained. With the much wider spacing (only 5 stimulations in two hours) which was adopted for the group experiments, these artifacts were greatly reduced. Except for the boredom attendant upon a longer session, still greater intervals might be profitably used.

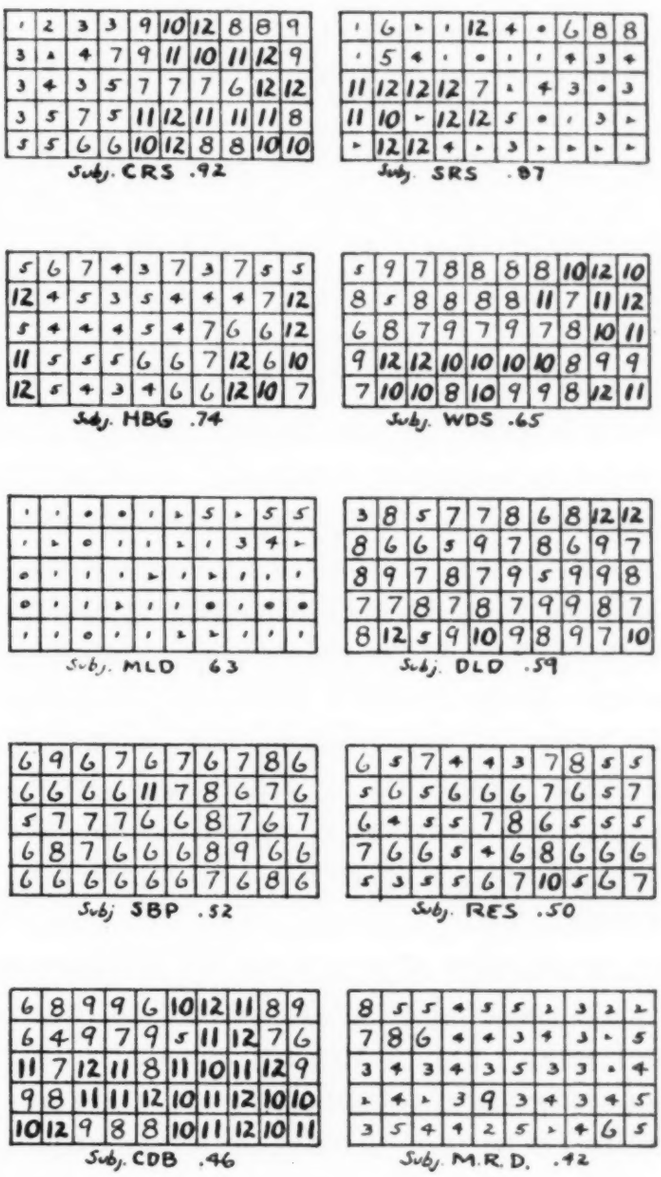

FIG. 4. Maps of average scores—2 mm stimulator.

The annoyance of lingering after-effects might be somewhat reduced by introducing a slower tempo of stimulation, instead of going from square to square without pause. It would then be necessary to work with a smaller total number of squares. To minimize the influence of irradiation, the stimulator must remain in contact for the shortest possible time. Approximately 3 seconds seems to be necessary to allow the experience to reach full intensity.

While various artifacts undoubtedly serve to reduce the reliability coefficients obtained with warm, there is some

evidence that warm-discrimination is *intrinsically more difficult* than the discrimination of cold. Primarily, this appears to be due to two factors:

1. The *range* of warm experiences from 46° C. stimulation seems to be much narrower than the range of cold experiences from 17° C. stimulation. In the case of cold, the average scores typically cover nearly the whole extent of the scale from 0 to 12, with a frequent piling-up at the top level indicating potentially a still wider discriminable range if more categories were used. In the case of warm, average scores covering the entire range are unusual. Furthermore, in most instances there is a foreshortening at *both* ends of the scale. Only rarely is there any piling up at the upper end, and the absence of 0's is notable. It is highly probable that this represents a narrower range of actual experiences, and not arbitrary action on the part of the subjects. Naturally, the narrower the range of experiences, the greater the difficulty of securing high reliability coefficients. It is significant that, in the 2 mm individual experiments, the only two subjects who had high coefficients also showed a wide range of average scores.

2. Warm sensitivity appears to be fundamentally more *changeable* than cold. This is indicated both by the wider general dispersion in Fig. 2 and the greater number of 'wild shots.' These might be caused by poor work on the part of the subjects, but the fact is that several subjects who had excellent records with cold did very poorly with warm. If the actual range of warm experiences is narrower, this might aggravate the variability. In the case of cold, at any rate, there is some indication that very strong and very weak squares tend to remain stable, while the intermediate ones are more changeable. If this holds true also for warm, the higher percentage of intermediate levels would encourage greater variability.

The most heartening result of this study is the apparent orderliness of the maps derived from average scores. In spite of lower reliability coefficients and greater general dispersion over a period of days, the *average scores may be*

just as significant with warm as they are with cold, if the results from a sufficient number of trials are used.

We may conclude, then, that seriatim warm-mapping can be a valuable research technique for quantitative study if precautions are taken to minimize the known artifacts and a sufficient number of periods is used in computing average scores. The basic problems for further investigation are similar to those already outlined for cold in the preceding article.[4]

Summary

When the results of Dallenbach's study of warm-mapping with trained observers (single mapping on four different days; 1 mm diam. stimulator at 44–46° C.) are replotted in terms of composite maps, the results are ambiguous as they were in the case of cold. If the concept of discrete 'warm spots' is discarded, however, the maps may be viewed as charts of orderly, but non-uniform, sensitivity. Consistency in mapping is thus implied, but not established, and the need of a seriatim technique is indicated.

Seriatim warm-mapping with 2 and 3 mm stimulators at 46° C. on the same basis as the cold-mapping previously reported (6 times an hour for a two-hour session) was found to involve serious artifacts from adaptation and vascular changes, although high reliability coefficients were obtained in a few cases. When only 5 stimulations were made during a two-hour period, better results were obtained, but still inferior to those secured with cold. Both the peak performances and the general level of the reliability coefficients were lower, and the charts of average against individual scores showed wider deviations and more 'wild shots.' However, it is significant that the maps derived from average scores show much the same orderly patterning as with cold. It is maintained that discrimination of warm experiences is essentially more difficult, probably because the range of actual experiences is narrower and the sensitivity itself more variable. With proper precautions, however, it is believed that seriatim warm-mapping can provide a useful technique for further research.

(Manuscript received August 30, 1938)

[4] *Op. cit.*